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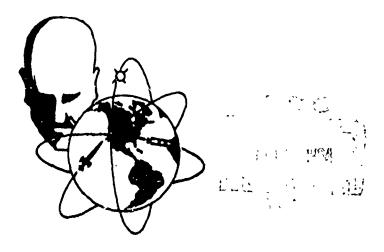
SPECIAL PERTURBATIONS WEIGHTED DIFFERENTIAL CORRECTION PROGRAM DOCUMENT

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-63-64.3 11 DECEMBER 1963

> J. D. Enright M. J. Kruger

496L SYSTEM PROGRAM OFFICE ELECTRONIC SYSTEMS DIVISION AIR FORCE SYSTEMS COMMAND UNITED STATES AIR FORCE

L. G. HANSCOM FIELD, BEDFORD MASS.



Prepared under Contract No. AF 19(628)-562 by Aeronutronic, a Division of Ford Motor Company, Newport Beach, California

FOR ERRATA

AD 4 2 6 0 3 5

THE FOLLOWING PAGES ARE CHANGES

TO BASIC DOCUMENT

HEADQUARTERS ELECTRONIC SYSTEMS DIVISION ACR FORCE SYSTEMS COMMAND UNITED STATES AIR FORCE

LAURENCE G. HANSCON FIELD

BEDFORD, MASSACHUSETTS 0173!

REPLY TO ESTI/TSgt Wreck/4535 ATTN OF:

2h July 196h

SUBJECT:

Page Revisions, ECD-TDR-63-645 SPWDC Program Document (AD 426 035)

 \mathtt{DDC}^{\bullet}

Cameron Station Alexandria, Va.

1. ESD-TDR-63-645, subject, Special Perturbation Weighted Differential Correction Program, was transmitted to DDC on 31 December 1963.

2. The attached page revisions are forwarded for inclusion in the basic report..

FOR THE COMMANDER

*Chief, Scientific and Technical Information Division

Revisal pages, 70, 72, 72a, 75, 78, 79, 83a, 83b, & 83c

DDC <u> हिस्तुम्बता गार</u>ा JUL 28 1964 एलिलिय DDC-IRA A

SUMMARY OF CURRENT SPWDC INPUT CARD FORMATS

the programs SPWDC and DESWGTE have undergone changes by agencies both at Colorado Springs and at Bedford which invalidate some of the input card formats as described in the program document. Although these changes have been documented through program change notes, some of the program users have not become aware of the changes in program operation because of the limited distribution of change notes. In order to summarize the format changes in a single source and to provide for adequate distribution, this men, has been prepared. Figures showing the revised formats for the changed cards are included. It is suggested that these be inserted into each copy of the SPWDC Program Document, (ESD-TDR-63-645).

With respect to observation precession, it should be noted that if column 80 of an observation card is blank, and it is an optical type, (right-ascension, declination) then it is precessed in accordance with the standard system technique. That is to say, that if right-ascension and declination are observed, and the equipment type is not 16, then it is precessed from the year which is indicated in column 70 to the present, and if it is a field reduced Baker-Nunn observation (equipment type 16) it is precessed from 1855 to the present if the declination is greater than -22 and from 1875 if it is less.

^{*} Prepared for the 496L SPO by Aeronutronic.

•	• •	* •	
Field, •	Column	Contents	. Code
1	1 - 8 •	"SPWDCAAA"	• • •
2	* 9 ₂ -*11	Satellite Number (optional)	
. 3	12	Auxiliary waight tape inputo (leno, 0=yes)
4 • •	•• •13 •	* Raw data observation tape input (0=no, 1	=yes)
5 *	14	Must always be blank for SPWDC.	••,
6	15	Print input observations prior to DC. (0	-no, 1-yes)
7	16 - 76 *	Not used.	
8 .	77	Weighting flag. (1=no, 0=yes)	
9	78 - 79 •	Always "AO",	
•• 10•	80	Always "P"	

Reference: CN T-311

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••	•		
Kield	*Column :	Contents *	. Code
1	. 1,	At integration mode (A=variable, 1=fixed)	2
`. 2 . ° °	° 2 - 11 · .	At (minutes) (positive makes correction enoch before obs., megative makes it after obs.)	3
٠3	12	Bulge perturbation flag	4
4 *	. 13	Drag perturbation flag	4.
5 •	14.	Radiation pressure perturbation flag	4 •
6	15	New epoch mode (0-rev, 1-time, 2-last ob.)	2 .
7	16 - 29	New epoch (day number in year and fraction, or revolution number.)	3.
" ,	30 - 36	Blements to correct: n, a, a, v, v, v, n, i, m	• 4
9	37 38°°	Number of times to repeat correction.	2
.10	39.	Aq check flag (used only if 6 or 7 elements are	•
••		being corrected.)	4
•11	40°- 47	Maximum hq (km) (used if col. 39 = 1.)	3
.12 *:	48 - 55 .	ABSHX (km)	3.
• 13 · •	36 - 63	ABSHX2* (km/sec)	3
14	° 64 - 71•	n (rms multiplier for rejection.)	3

•.	Pield	Cølumn	Contents	Code	:
	15	72	Residual output flag (0-never, 1-first and last passes only, 2-all passes.)	2	
	• 16	73 .	Special "n and U" correction on first pass.	4	
	•17	34 - 77 •	Relative change in successive rms's to determine convergence. (if blank, .05 is used.)	3	•
	18 •	78 - 79	Always"Δ3"	•	
	19	• 80	Always "P".		

PIGURE 19. DIFFERENTIAL CORRECTION GONTROL CARD, Part 2 of 2 .

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Field	Column	Contents	Code
1	1	Ateintegration mode (A=variable, 1=fixed)	?
2	2 - 11	At (minutes) (sign determined from FP card.)	3
3 ·	12	Bulge perturbation flag	4
4	e 13 [°]	Drag percurbation flag	4
5	• 14	Radiation pressure perturbation flag *	4
• 6	. 15 - 16	Print d lag $\begin{cases} 1 - t, \underline{r}, \underline{t} & \bullet \\ 2 - t, a, e, i, \Omega, \omega, U \end{cases}$ Add flags $\begin{cases} 4 - t, \beta, \lambda_{E}, h \end{cases}$ of data.	for lon 2
7	• • 14	Binary ephemoris taps output flag	4
8	18	Prediction reliability output flag	4
9	. 19	Punched cards (t, r) (Also leaves data in core for later use by GIPAR)	4
10	20 - 77	Not used.	
11	78 - 79 °	Always "A6".	`
• 12	80	Always, "P".	

FIGURE 22. TIME PREDICTION CARD \$1

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	Field	Column *	Contents	i e
	1	1 - 4	Sensor number ©	1.
•	2	• 5 - 11 • °	Station latitude (deg. north) (assumed dec. pnt.)	3
	3	12 - 19	Station longitude (deg. west) (assumed dec. pnt.)	3
	4	20 - 25	Station altitude (meters) (assumed dec. pnt.)	3
	5	. 26 - 77	Not used.	
	6	78 - 79	Always "A9".	
	7	80	Always "P".	

Note: Trailing, zeros must be punched in fields 2 and 3.

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F	ield	Column	Contents	Code
•	1	1.0	DC Flag	. 4 •
•	2	2	Prediction (0-no)(1-Time)(2-Station)	2
	3	3	Of the second o	2
	a		1 - Print also $\Delta \rho$, $\rho \cos \delta \Delta \alpha$, $\rho \mu \delta$, $\Delta \dot{\rho}$ for "n and U" correction pass.	•
	•		2 - Print Δρ, cosδάα, Δδ, Δρ, in degrees for all passes.	
•		• •	3 - Make only one pass. Additional residuals in U,V,W coordinates are computed and printed, as well as residual means and standard deviations for each of the sensors.	
		•	4 - Like option 3 except that residuals in obsequentities are punched on cards as well as prin (Format given in CN T-313.)	
•	4	4 - 77	Not used.	
_	5●	78 ⁷ - 79	Always "10".	
	6	80	Always "P".	_
				•

FIGURE 26. PROGRAM EXECUTION CARD

Reference: CN R-188 with attachments.

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• Field	Column	Contents	Crise
• 1	1 - 3	Sensor number	1
2	4 - 5	Always "11",	
• 3 •	6 - 8	Not used.	
4	9 - 16	Always "CSGBIASA"	
5	17 - 24	Range standard deviation (km)	3
6 e	25 - 32 •	Range bias (km)	3
7	33 - 40	Range-rate standard deviation (km/sec)	3
8	41 - 48	Range-rate bias (km/sec)	3
9	49 - 56	Azimuth (or rt. asc.) standard deviation (deg)	3 •
e 10	57 - 64	Azimuth (pr ft. asc.) bias (deg)	3
11	65 - 72	Elevation (or decl.) standard deviation (deg)	3
12	73	Multiple punch (11-8-2)	
13	74 - 80	Not used.	

FIGURE 30A. CSGBIAS FUNCTION WEIGHTING CARD #1 -83a-

Reference: CN K-188 with strachments.

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Field	Column	Contents	Code
1	1 - 3	Sensor number	1
2	4 - 5	Always "10".	
3	6 - 8	Not used.	
4	9 - 16	Always "CSGBIASA"	
5	17 - 24	Elevation (or decl.) bias (deg)	3
6	25 - 32	Observation time bias (sec)	3
7	33 - 40	Not used	•
8	41	Multiple punch (11-8-2)	•
9	42 - 80	Not used	•

FIGURE 30B. CSGBIAS PUNCTION WEIGHTING CARD #2

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7ield	Column	Contents	Code.
1	1 - 3	Sensor number	1
2 3	4 - 5	Always "10". •	_
3	6 - 8	Not used.	
4	9 - 16	Always "SIGTAB1A"	• *
5	17 - 24	Alternate value selector (anywhere in field) 0 or A - Primary value	2
		1 - 1st alternate value if compiled in 2 - 2nd alternate value if compiled in	
6	25 - 32	Scale factor. All tabular values of standard de are multiplied by this factor. (If blank, a value one is assumed.)	
7	33 - 40	Range bias (km)	9 3
8	41 - 48	Elevation (or decl.) bias. (deg)	3
9	49 - 56	Azimuth (or rt. asc.) bias. (deg)	3 3 3
10	57 - 64	Range-rate bias. (km/sec)	3
11	65 - 72	Observation time bias. (min.)	3
12	73 - 79	Not used.	
13	80	Multiple punch (11-8-2)	

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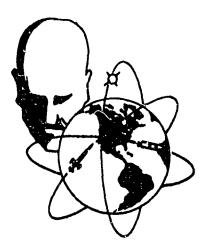
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SPECIAL PERTURBATIONS WEIGHTED UIFFERENTIAL CORRECTION PROGRAM DOCUMENT

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-63-645 11 DECEMBER 1963

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ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. HANSCOM FIELD, BEDFORD MASS.



Prepared under Contract No. AF 19(628)-562 by Aeronutronic, Division of Ford Motor Company, Newport Beach, California

FOREWORD

Contractor's Report Publication No. U-2370

ESD-TDR-63-645

SPECIAL PERTURBATIONS WEIGHTED DIFFERENTIAL CORRECTION PROGRAM DOCUMENT

ABSTRACT

This report describes a computer program which differentially corrects and/or predicts the orbit of a geocentric satellite. The dynamics of the program are based on a variation of parameters formulation with the perturbative acceleration being numerically integrated. A weighted correction process is incorporated which considers the relative accuracy of the observational data in a least-squares fit. Included in the document are the program description, complete formulation, program operating instructions, flow diagrams, and test cases.

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SECTION 1

INTRODUCTION

Aeronutronic has developed an operational weighted differential correction program, using the special perturbations variation of parameters approach. Operating under the 496L B-2 Semi-automatic Programming System, the program will accept sensor observations, assign weights to the data, perform a differential correction and predict future position and velocity.

The purpose of the Special Perturbations Weighted Differential Correction (SPWDC) Program is to provide highly precise predictions of satellite position. The operational capability to utilize weights when performing a differential correction in addition to the highly accurate Special Perturbations formulation will provide far more accurate position prediction than the Simplified General Perturbations approach. The latter concept was designed to provide sufficient accuracy to maintain surveillance on all earth satellites with minimum computer time requirements. This surveillance mission requires only such accuracy as fo ensure acquisition and recognition of every satellite by sensors capable of observing it.

The SPWDC Program, therefore, supplies a means for correcting orbital parameters and predicting in an extremely accurate fashion for missions requiring precise position determination. Operationally, it functions in the B-2 System running in the Schedule Tape Mode.

Section 2 of this document is a description of the SPWDC Program. The formulation by which the program generates the numerically integrated position is given in Section 3 of the report. Operating instructions are detailed in Section 4, with parameter card formats shown in Appendix I. The main flow of the program is diagramed in Section 5, and detailed flow data in Appendix II. Compiled test cases are outlined in Section 6. A glossary of terms will be found in Appendix III.

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SECTION 2

PROGRAM DESCRIPTION

The SPWDC Frogram contains three main functions. These functions, shown schematically in Figure 1, are: OBSERVATION WEIGHTING, DIFFERENTIAL CORRECTION, and PREDICTION. Each of these functions is iescribed here, in terms of its general features, required parameters, and function controls both internal and output. Required parameters are those numerical quantities describing the physical conditions to be simulated in the program. Internal controls are those quantities which specify the program logic to be executed, and output controls are those quantities prescribing the choice of available output.

2.1 OBSERVATION WEIGHTING

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The Observation Weighting function of the program is to reformat input observations, assigning to each observed quantity its standard deviation. These accuracy estimates are provided to the routine in three ways:

- By assigning a constant accuracy estimate for all observations from a given sensor;
- (2) By assigning an accuracy estimate to each observation being used; or
- (3) By indicating a programmed weight function which is used to compute the observation parameters.

The assignment of weight factors to the observations may be made by any combination of the above methods, with the restriction that any given sensor will use only one of three choices.

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FIGURE 1. SPWLC PROGRAM FUNCTIONS

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After the complete set of observations has been examined and each weight assignment has been made, the observations are ordered chronologically. This feature is necessary in the Observation Weighting function in order to ensure an efficient correction process. Since the correction program must represent the observations at each actual observation time by numerically integrating to that time, it is highly desirable that the observations be ordered in time so the integration takes place entirely in one direction.

a. Observation Weighting Parameters

Observations are supplied by:

- (1) Standard SPS Observation Card, or
- (2) SRADU tape.

Weighting information is supplied by the Weighting Tape (see Section 4).

b. Observation Weighting Controls

Internal controls are as follows:

- (1) Weighting information may be picked up either from the Weighting Tape, or a set of accuracy estimates may be compiled into the Observation Weighting Program in the weight by sensor mode. Normally, the former selection will be made; however, it may be to the user's advantage to program the sensor weight values for automatic internal assignment.
- (2) Weighting data may or may not be assigned to the observations. It should be noted that if weights are to be assigned, they must be assigned to <u>all</u> observations. It is not possible to mix weighted and unweighted data.
- (3) A selection of weighting mode is required to indicate the choice of weighting by sensor, by observation, or by function.

No output controls are available to the Observation Weighting function.

2.2 DIFFERENTIAL CORRECTION

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The Differential Correction function accepts the reformatted observations from the Observation Weighting function and performs a weighted or unweighted differential correction on the orbit element set. Ephemeris computation is carried out in a special perturbations variation of parameters formulation. This formulation numerically integrates the perturbative accelerations influencing the parameters of an instantaneous two-body reference orbit.

The numerical integration is performed by a fourth-order Runge-Kutta integration routine. A fixed step size may be specified for this numerical integration, or it may be used in a variable mode. In the variable mode, the initial step size is specified and subsequently increased or decreased internally, based on error control parameters.

Perturbations handled by the program include: zonal harmonic bulge, atmospheric drag, and solar radiation pressure. These effects may be controlled to incorporate any combination in a particular case.

A correction can be obtained for any of the six orbit elements, and may also include the satellite mass. This latter parameter actually represents a correction on the ballistic parameter $\frac{C_DA}{D}$, where $\frac{C_DA}{D}$ is the

drag coefficient, A is the satellite cross-sectional area, and m is the satellite mass.

First-order partials relating variations in observed quantities to variations in orbit parameters are the basis of the correction equations. The correction for mass, or ballistic parameter, uses an equation derived on the assumption of near circular eccentricity. Therefore, for the general case, a variant orbit approach is used, whereby the satellite mass is varied and a complete integration is performed. This ephemeris is then used to form numerical partials between the observed quantities and the variation in mass.

Special correction passes may be taken. For instance, it may be desirable to correct the mean motion initially before attempting a complete correction. This will reduce the timing residual and provide a better fit on subsequent correction passes. Also, an incernal check has been built in which examines the change in the perigee distance between successive corrections. If the perigee distance varies too

greatly, the correction is automatically repeated without correcting the orbital eccentricity. This prevents a possible divergent correction which may occur due to non-linear drag effects.

The correction process will repeat up to a maximum number of iterations, or until the root-mean-square (RMS) of the accepted residuals has converged within 5% comparing successive values. Accepted residuals are those that are not rejected on the basis of an absolute maximum or a relative check based on a limit of 1.5 times the residual RMS. In a weighted differential correction this is the weighted RMS; however, the convergence check is still against the unweighted value. In addition, weighted runs always perform an unweighted correction on the first iteration in order to fit the elements as well as possible before applying weight data. An option is also provided, enabling the post correction epoch to be updated to a specific revolution number or time.

a. Differential Correction Parameters

Orbit elements are supplied by:

- (1) The standard card format, or
- (2) The SEAI file.

Vehicle data are mass, diameter, and reflectivity.

b. Differential Correction Controls

Internal controls are as follows:

- The integration mode, variable or fixed, is specified.
- (2) The integration step size is specified. If the mode is variable, then this denotes the initial step size.
- (3) Selection of perturbations to be used: bulge, drag, radiation pressure.
- (4) Specification of the new epoch:
 - (a) Revolution number (actual number, not referenced to current epoch)
 - (b) Time (absolute), or

- (c) Time of last observation.
- (5) Specification of the elements to be corrected Any combination may be selected; however, in some instances the corrections are not independent and will influence the other parameters.
- (6) Special correction passes:
 - (a) Correct mean motion only on first pass
- (b) Maximum value allowed for change in perigee distance
- (7) Specification of rejection criteria:
 - (a) Absolute maximum for displacement residuals,
 - (b) Absolute maximum for range-rate residuals, and
 - (c) Multiplying factor applied to the residual RMS for relative rejection.
- (8) Error co ols for Runge-Kutta integration:
 - (a) Absolute controls
 - (b) Relative controls

One output control is available to the Differential Correction function. This establishes the frequency of output of the residuals as: never, first and last set, or every set.

2.3 PREDICTION

The Prediction function of the program may be used to obtain future position and velocity data from an input element set or a corrected set from the Differential Correction function. Two methods are provided for the specification of the prediction time. A series of prediction points may be specified by time or by the closest point of approach to some 'ocation on the earth.

Ephemeris computation in the Prediction function is carried out in the same manner as in the Differential Correction, i.e., using a special perturbations variation of parameters formulation where the integration is according to a fourth-order Runge-Kutta process. The mode of integration, integration step size, and the perturbations to be considered must be supplied.

In addition to the prediction, this function has the capability of estimating the reliability of the prediction point. The reliability check computes the variance in both inertial and radial, transverse and orthogonal components of position and velocity. It is based on the variance-covariance matrix of orbit elements derived from the Differential Correction function.

a. <u>Prediction Parameters</u>

Prediction by time requires the following parameters:

- (1) Initial prediction time (absolute)
- (2) Prediction interval (minutes)
- (3) Number of points to be obtained

Prediction by station pass requires the following parameters:

- A station number identification. This would pertain to the SEAI File designation if the location is to be one of the SPADATS sensors. Otherwise, any number designation will suffice.
- (2) Latitude, longitude (west), and altitude of the station, required if the SEAI File is not being used.
- (3) The length of time to simulate the ephemeris on either side of the closest point of approach.
- (4) The maximum elevation angle below which no ephemeris data will be obtained. This takes precedence over item (3) above.
- (5) The interval of time to be used in obtaining the ephemeris.
- (6) The number of passes to be considered.

b. Prediction Controls

Internal controls are as follows:

- The integration mode, variable or fixed, is specified.
- (2) The integration step size is specified. As in the Differential Correction, if the mode is variable, then this denotes the initial step size.
- (3) Selection of perturbations to be used: bulge, drag, radiation pressure.

Output controls are as follows:

- (1) Print any combination of
 - (a) time, position, and velocity (t, x, y, z, \dot{x} , \dot{y} , \dot{z})
 - (b) time, osculating elements (t, a, e, i, Ω , ω , L)
 - (c) time, ground track data (t, satellite latitude, satellite east longitude, and satellite altitude)
 - (d) time, look angles (t, range, range-rate, azimuth, elevation) available only for station pass prediction
- (2) Print reliability estimate consisting of the standard deviation in the position and velocity predictions in inertial coordinates and orbital coordinates.
- (3) Prepare a binary ephemeris tape containing t, x, y, z, \dot{x} , \dot{y} , \dot{z} .
- (4) Punch position cards containing t, x, y, z.

SECTION 3

FORMULATION

$$h_{x_{0}} = \sqrt{p_{0}} \quad \sin \Omega_{0} \sin i_{0}$$

$$h_{y_{0}} = \sqrt{p_{0}} \quad \cos \Omega_{0} \sin i_{0}$$

$$h_{z_{0}} = \sqrt{p_{0}} \quad \cos i_{0}$$

where p is the semi-latus rectum, Ω is the right ascension of the ascending node, and io is the orbital inclination (see Figure 2). The subscript identities these quantities as the orbital parameters at epoch, t. These parameters do not exhibit singularities at zero eccentricity. A parameter adoption in the differential correction section of the program effectively limits the program application to orbits having inclinations greater than two degrees.

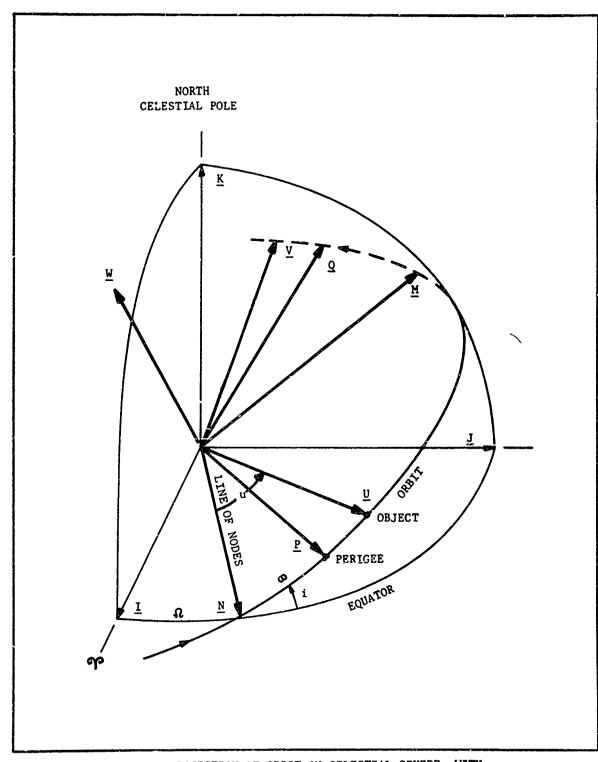


FIGURE 2. PROJECTION OF ORBIT ON CELESTIAL SPHERE, WITH ORIENTATION UNIT VECTORS AND ANGLES DISPLAYED

The formulation accounts for perturbations due to drag forces and the primary effects of the Earth's asphericity (1) * and to radiation pressure (2). The elements L_{o} , n_{o} , a_{xNo} , and \underline{h}_{o} vary from point to point on the resulting ephemeris in such a manner that they satisfy a system of differential equations in the dependent variables, the elements, and the independent variable, time, t. The solution to the system of differential equations is achieved in a numerical integration process, executed by means of the Runge-Kutta procedure. The program proceeds to evaluate the elements from point to point by using either a fixed grid size for the variable t or a variable grid size controlled by the program.

The program will function in a differential correction mode and/or an ephemeris mode. In the differential correction mode, a given set of elements is improved and updated by means of a least-squares fit to a set of observations. These observations may be a weighted set or an unweighted set with the correction functioning accordingly. In the prediction mode, future position and velocity data are provided by integrating to the specified point, using the corrected set of elements or an element set introduced for the purpose of prediction only.

3.1 OBSERVATION WEIGHTING

One of the basic considerations to be included in the development of accurate Special Perturbations programs is that of assignment of weighting factors to all observations for subsequent use in the differential correction process. Because of the restrictive core allocation imposed by the operational system, the weight assignment is performed independent of the remainder of the processing.

The two main design features of the resulting proprocessing program are (1) to reformat the observational data, adding weights for all the quantities, and (2) to order the observations in time, for either a forward or backward integration.

These design criteria were incorporated into the observation weighting function (OBSWGT) of SPWDC. The functional flow between OBSWGT and SPWDC is shown in Figure 3. The general specifications of the program are:

^{*}Superscripts indicate References at end of document.

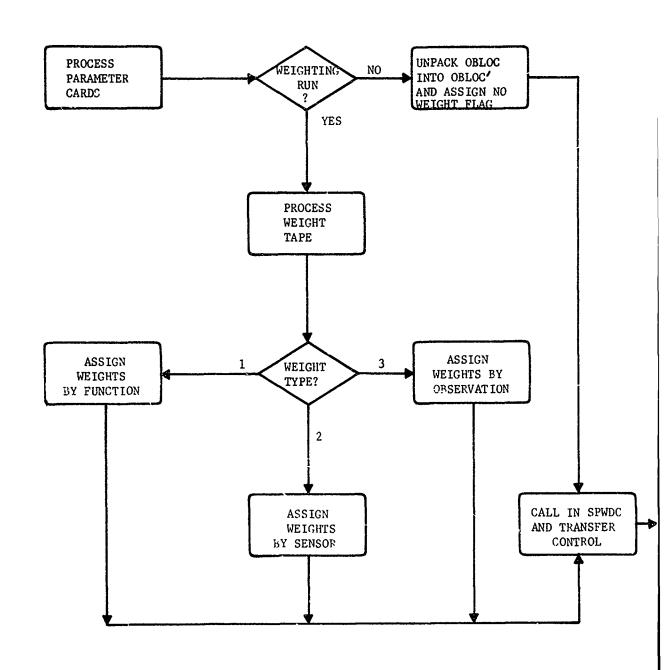


FIGURE 3. OBSWGT FUNCTIONAL FLOW

- (1) OBSWGT will operate <u>before</u> the Special Perturbation Program. OBSWGT will apply weights to all the observations, leave the observations in core, and call (and exit to) SPWDC from the master program tape.
- (2) OBSWGT will operate as a schedule tape job. Standard input will consist of combinations of parameter, element, sensor and observations cards.
- (3) Additional input data will be contained on an auxiliary tape. Data on this tape will contain weight factors for each sensor and/or observation or will contain controls for determining the method to be used for computing the weights. Operationally, this will be known as the Weighting Tape.
 - (a) A single set of weights (at most, four quantities) can be specified for a sensor. These weights then apply to all observations reported by the sensor.
 - (b) A single set of weights can be specified for each observation.
 - (c) A routine can be specified by sensor to <u>compute</u> weight factors for each observation reported by the sensor.
- (4) A subroutine will be made available to the Special Perturbation program to retrieve the observation quantities, weight factors, and to retrieve the required sensor data.
- (5) The routines for computing weight factors (mentioned in (3) (c) above) will have a standard calling format and be contained as a subroutine in the OBSWGT program. These routines can only be added, deleted, or changed by recompilations. However, the parameters used by the routines can be changed (specified as input quantities) prior to each run.
- (6) All weighting procedures will be general so that the specific function to be applied is determined on the Weighting Tape by pairing a sensor with a function as an input quantity. In this way routines can apply to more than one sensor, reducing duplication of routines.
- (7) A special bypass mode will be available to process observations without applying weight factors.

3.2 VARIATION OF PARAMETERS EPHEMERIS COMPUTATION

The following paragraphs detail the formulation of the representation, accelerations, and integration of the orbit. The representation calculates position and velocity at a given time from the orbital parameters. The accelerations are computed from the force field formulation. The integration is performed upon the derivatives of the orbital parameters.

a. Representation

(1) Initialization

Prior to any calculations, the epoch elements must be determined from the input. Since the input is either in the form of 7 element cards or from the SEAI tape, the system subroutine NXTELM is used.

Given the epoch parameter set, the following computations are performed:

$$p_{o} = \frac{h_{o} \cdot h_{o}}{1 \cdot v_{o}}$$

$$\frac{W_{o}}{\sqrt{p_{o}}} = \frac{h_{o}}{\sqrt{p_{o}}}$$

$$cos i_{o} = W_{z_{o}}$$

$$i_{o} = arc tan \left[\frac{sin i_{o}}{cos i_{o}} \right]$$

$$sin \Omega_{o} = \frac{W_{x_{o}}}{sin i_{o}}$$

$$cos \Omega_{o} = \frac{w_{y_{o}}}{sin i_{o}}$$

 $\Omega_{\rm o} = \arctan \frac{\sin \Omega_{\rm o}}{\cos \Omega_{\rm o}}$

$$e_{o}^{2} = a_{xN_{o}}^{2} + a_{yN_{o}}^{2}$$

$$e_{o}^{2} = \frac{P_{o}}{1 - e_{o}^{2}}$$

$$U_{o} = L_{o} - \Omega_{o} \qquad \text{if } W_{z_{o}} \ge 0$$

$$L_{o} + \Omega_{o} \qquad \text{if } W_{z_{o}} < 0$$

$$n_{o} = \frac{\sqrt{\mu} k_{e}}{a_{o}^{3/2}}$$

$$a_{x_{o}} = a_{xN_{o}} \cos \Omega_{o} - a_{yN_{o}} \sin \Omega_{o} \cos i_{o}$$

$$a_{y_{o}} = a_{xN_{o}} \sin \Omega_{o} + a_{yN_{o}} \cos \Omega_{o} \cos i_{o}$$

$$a_{z_{o}} = a_{yN_{o}} \sin i_{o}$$

$$q_{o} = a_{c} (1 - e_{o})$$

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If the input mass parameter = 0, mass is set equal to 1. The quantity 1/mass is formed.

(2) Position and Velocity

At each time point, whether at an integration step, observation time or prediction point, a similar initialization takes place. Then, the program goes on to compute the geocentric position (\underline{r}) and velocity $(\underline{\dot{r}})$ of the satellite. (1)

Given
$$\underline{a}$$
, \underline{h} , \underline{L} , compute \underline{r} , $\underline{\dot{r}}$

$$p = \underline{h} \cdot \underline{h}$$

$$e^2 = \underline{a} \cdot \underline{a}$$

$$a = \frac{p}{1 - e^2}$$

$$n = \frac{k_e \sqrt{\mu}}{a^{3/2}}$$

$$\underline{\underline{W}} = \frac{\underline{\underline{h}}}{\sqrt{\underline{p}}}$$

T Case

$$W_z = \cos i$$

$$M_z = \sqrt{1 - W_z^2} = \sin i$$

$$N_{x} = -\frac{W_{y}}{M_{z}}$$

$$M_y = N_x W_z$$

$$N_y = \frac{W_x}{M_z}$$

$$M_x = -N_y W_z$$

$$N_z = 0$$

$$a_{xN} = \underline{a} \cdot \underline{N}$$

$$a_{yN} = \underline{a} \cdot \underline{M}$$

$$\Omega = \arctan \frac{N_y}{N_x} = \arctan \frac{W_x}{-W_y}$$

$$u = L - \Omega \quad \text{if} \quad W_z \ge 0$$

$$\mathbf{L} + \Omega$$
 if $\mathbf{W_z} < 0$

$$0 \le U < 2\pi$$

Kepler's equation is solved by iteration using the Newton-Raphson method with an initial guess for (E+ ω) of U [i.e., (E+ ω)] = U]

$$(E+\omega)_{i+1} = (E+\omega)_i - \frac{[U+e \sin E_i - (E+\omega)_i]}{e \cos E_i - 1}$$
 radians

where

Section 1

e cos
$$E_i = a_{xN} \cos (E+\omega)_i + a_{yN} \sin (E+\omega)_i$$

e sin $E_i = a_{xN} \sin (E+\omega)_i - a_{yN} \cos (E+\omega)_i$

The iteration is concluded when

$$\left| (E + \omega)_{i+1} - (E + \omega)_{i} \right| < 10^{-8}$$

If, after 50 iterations, the criterion is not met, the run is terminated. A comment to this effect is written on the output tape.

After Kepler's equation is solved, the calculations continue:

$$r = a (1 - e cos E)$$

$$\dot{r} = \frac{\sqrt{\mu \cdot a}}{r}$$
 (e sin E)

$$r\dot{v} = \frac{\sqrt{\mu \, a}}{r} \sqrt{1 - e^2}$$

$$\cos u = \frac{a}{r} [\cos (E + \omega) - a_{xN} + a_{yN} \frac{e \sin E}{(1 + \sqrt{1 - e^2})}]$$

$$\sin u = \frac{a}{r} [\sin (E + \omega) - a_{yN} - a_{xN} \frac{e \sin E}{(1 + \sqrt{1 - e^2})}]$$

$$\underline{\mathbf{U}} = \underline{\mathbf{N}} \cos \mathbf{u} + \underline{\mathbf{M}} \sin \mathbf{u}$$

$$\underline{V} = -\underline{N} \sin u + \underline{M} \cos u$$

$$\underline{\mathbf{r}} = \mathbf{r} \ \underline{\mathbf{U}}$$

$$\underline{\dot{r}} = \dot{r} \underline{U} + r\dot{v} \underline{V}$$

b. Drag

To compute the drag perturbation, it is first necessary to calculate H, the altitude above an oblate spheroid:

$$H = (r - 1) - \frac{3}{2} f^2 (U_z)^4 + (f + \frac{3}{2} f^2) U_z^2$$

For this altitude the 1962 U.S. Standard Atmosphere Table is searched for the density (ρ_r) and molecular weight (M_o) .

Values above 760 km are obtained by linear extrapolation.

The acceleration is obtained by the following computation (1):

$$v_{x} = \dot{x} + y\dot{\theta}$$
 where $\dot{\theta} = 0.058 834 47 \text{ radians/k}_{e} \text{ min}$

$$v_{v} = \dot{y} - x \dot{\theta}$$

$$v_z = \dot{z}$$

$$v = \sqrt{v_x^2 + v_y^2 + v_z^2}$$

$$T_{s} = \frac{\rho_{r} c_{D} (v_{co})^{3} \nu^{3}}{4 e \sigma_{s}} + (300)^{4}]^{1/4}$$

$$C = \frac{6.972 \times 10^9 \text{ } \nu \text{d}}{C_{D_0} \sqrt{M_e T_s}}$$

if
$$c_{\rho} > 1418$$
, $c_{\rho} = c_{D_{\rho}}$

otherwise,

$$c_{D} = c_{D_{O}} (1 + 1.1739130 e^{-C\sigma})$$

 $c_{D_{C}} = c_{D_{O}} \rho_{T} \nu (-\frac{K \pi d^{2}}{8m})$

$$\dot{x}_{D} = D_{c} \nu_{x}$$

$$\dot{y}_{D} = D_{c} \nu_{y}$$

$$\dot{z}_{D} = D_{c} \nu_{z}$$

c. Asphericity (Bulge)

The acceleration $(\dot{\underline{r}}_B)$ due to the zonal harmonics of the Earth's gravitational potential are calculated by

$$\dot{x}_{B}^{\prime} = x \left[\frac{\mu}{r^{3}} \sum_{n=2}^{7} J_{n} \left(\frac{a_{e}}{r} \right)^{n} P'_{n+1} \left(U_{z} \right) \right]$$

$$\dot{\hat{y}}_{B} = y \left[\frac{\mu}{r^{3}} \sum_{n=2}^{7} J_{n} \left(\frac{a_{e}}{r} \right)^{n} P'_{n+1} \left(U_{z} \right) \right]$$

$$\dot{z}_{B}^{\prime} = z \left[\frac{\mu}{r^{3}} \sum_{n=2}^{\infty} J_{n} \left(\frac{\frac{a}{e}}{r} \right)^{n} P_{n+1}^{\prime} \left(U_{z} \right) \right]$$

$$-\frac{\mu}{r^2}\sum_{n=2}^{7}J_n\left(\frac{\frac{a}{e}}{r}\right)^nP_n'\left(U_z\right)$$

where
$$P_0(U_z) = 1$$
, $P_1(U_z) = U_z$

and
$$P_{n}(U_{z}) = \frac{1}{n} [(2n - 1) U_{z} P_{n-1}(U_{z}) - (n-1) P_{n-2}(U_{z})]$$

$$P'_{n}(U_{z}) = \frac{1}{U_{z}^{2}-1} \quad n[U_{z} P_{n}(U_{z}) - P_{n-1}(U_{z})]$$

$$n \ge 2$$

The coupling factors used are (5):

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d. Radiation Pressure

The acceleration due to direct solar radiation pressure, $\dot{\underline{r}}_{RP}^{\prime}$, is formulated as detailed in Reference 2. Initially, the mean longitude of the sun at the beginning of the current year $L_{\Theta O}$ is found by the system subroutine $TLC^{(3)}$:

$$\begin{split} \mathbf{L}_{o} &= \mathbf{L}_{oo} + \mathbf{n}_{o} \ (\mathbf{t} - \mathbf{t}_{o}) \\ \mathbf{M}_{o} &= \mathbf{L}_{oo} + \mathbf{n}_{o} \ (\mathbf{t} - \mathbf{t}_{o}) - \pi_{o} \\ \boldsymbol{\ell}_{o} &= \mathbf{L}_{oo} + \mathbf{n}_{o} \ (\mathbf{t} - \mathbf{t}_{o}) + 2 \ \mathbf{e}_{o} \ \sin \, \mathbf{M}_{o} + \frac{5}{4} \ \mathbf{e}_{o}^{2} \ \sin \, 2\mathbf{M}_{o} \\ \mathbf{L}_{x_{o}} &= \cos \, \boldsymbol{\ell}_{o} \\ \mathbf{L}_{y_{o}} &= \cos \, \boldsymbol{\epsilon} \ \sin \, \boldsymbol{\ell}_{o} \\ \mathbf{L}_{z_{o}} &= \sin \, \boldsymbol{\epsilon} \ \sin \, \boldsymbol{\ell}_{o} \\ \cos \, \psi &= \frac{\mathbf{L}_{o} \cdot \mathbf{r}}{\mathbf{r}} \\ \dot{\mathbf{x}}_{RP}^{*} &= (\frac{\mathbf{r}_{o}}{M}) \ \mathbf{L}_{xo} \\ \dot{\mathbf{y}}_{RP}^{*} &= (\frac{\mathbf{r}_{o}}{M}) \ \mathbf{L}_{yo} \\ \dot{\mathbf{r}}_{RP}^{*} &= (\frac{\mathbf{r}_{o}}{M}) \ \mathbf{L}_{zo} \end{split}$$

If $\cos\psi$ > 0, the satellite is illuminated.

If $\cos \psi < 0$, form $\sin (\psi + \eta) = \sin \psi \cos \eta + \sin \eta \cos \psi$

$$= \sqrt{(\cos^2 \psi - 1)(\frac{1}{r^2} - 1)} \div (\frac{1}{r}) \cos \psi$$

If $\sin (\psi + \eta) > 0$, the satellite is illuminated.

If the satellite is illuminated, calculate

$$\dot{x}_{R\Gamma}' = (\frac{F_{\odot}}{M}) L_{x\odot}$$

$$\dot{y}_{RP} = (\frac{F_{o}}{M}) L_{yo}$$

$$\dot{z}_{P,P}' = (\frac{F_{\odot}}{M}) L_{z_{\odot}}$$

e. Derivatives and Integration

The total perturbative acceleration can now be used to determine the perturbative derivatives of the parameters.

$$\underline{\dot{r}}' = \underline{\dot{r}}'_B + \underline{\dot{r}}'_D + \underline{\dot{r}}'_{RP}$$

$$r\dot{r} = \underline{r} \cdot \underline{\dot{r}}$$

$$\dot{s}\dot{s} = \dot{\underline{r}} \cdot \dot{\underline{r}}$$

$$r\dot{r} = \underline{r} \cdot \dot{\underline{r}}$$

$$D = \frac{r\dot{r}}{\sqrt{\mu}}$$

$$\mathbf{D}' = \frac{\mathbf{r}\dot{\mathbf{r}}'}{\sqrt{\mu}}$$

$$\dot{\mathbf{p}}' = \frac{2\dot{\mathbf{s}}\dot{\mathbf{s}}'}{\sqrt{u}}$$

$$r\dot{b} = \underline{w} \cdot \dot{\underline{r}}$$

$$\hat{\ell} = \frac{z(r\dot{b})}{(1+W_z)\sqrt{\mu^p}}$$

$$\underline{\underline{\mathbf{a}}} = \frac{(\underline{\mathbf{D}}\underline{\underline{\mathbf{r}}} - \underline{\mathbf{D}}\underline{\underline{\underline{\mathbf{r}}}}) - \underline{\mathbf{D}}\underline{\underline{\mathbf{r}}})}{\sqrt{\mu}}$$

$$eQ = \underline{W} \times \underline{a}$$

$$-e^{2}v = eQ \cdot \underline{a}$$

 $L' = \ell' - \frac{2D'}{\sqrt{a}} - \left[\frac{e^{2}v'}{1 + \sqrt{1 - e^{2}}}\right]$

$$\underline{\mathbf{h}'} = \frac{\underline{\mathbf{r}} \times \underline{\dot{\mathbf{r}}}'}{\sqrt{\mu}}$$

The derivatives, as used in the Runge-Kutta routine (3), are:

$$\frac{dL}{dt} = k_e L + n$$

$$\frac{d\underline{a}}{dt} = k_e \ \underline{a}'$$

$$\frac{d\underline{h}}{dt} = k_e \underline{h}'$$

3.3 WRIGHTED DIFFERENTIAL CORRECTION

It is necessary to simulate observations in two phases of the SPWDC. The most obvious phase is that of prediction. Also, in the differential correction, the estimate of the observed quantities on the basis of the current parameter estimates must be obtained. This estimate is often referred to as the "computed" quantity as distinguished from the "observed" quantity. The difference between these quantities is the "residual," e.g., for the ith range observation

$$\Delta \rho_i = \rho_i$$
 (observed) - ρ_i (computed)

Each residual is related to corrections in the parameters by an "equation of condition," e.g.,

$$\Delta \rho_{i} = \sum_{j=1}^{7} \frac{\partial \rho_{i}}{\partial p_{j}} \Delta p_{j}$$

where p_j are the parameters n_0 , a_{xN_0} , etc.

These equations of condition are weighted, according to the numbers obtained as outlined in Section 3.1, and processed as described in the present section by relating the "computed" quantities to the geocentric ephemeris obtained as described in Section 3.2. This relationship involves the location of the center of the Earth with respect to the observing station, $\underline{\mathbf{R}}$:

$$\underline{\rho} = \underline{r} + \underline{R}$$

The partial derivatives with respect to the seven parameters are computed according to analytical formulas, given in the following subsections. When the eccentricity exceeds a given maximum, however, the coefficients of the ballistic parameter are computed by a variant ephemeris. During this calculation the quantities $\rho_{\rm V}$, $\underline{\rm L}_{\rm V}$, and $\dot{\rho}_{\rm V}$ are stored in a bloc designated VDATA. The v subscript is used hereafter to identify these results of the variant calculation. The variant ephemeris differs from the nominal ephemeris by using a ballistic parameter differing from the nominal value. This varia-

tion in the ballistic parameter $\delta\left(\frac{C_D^A}{m}\right)$ is represented in the following

formulation by its factor $\delta(\frac{1}{m})$. Therefore, the factor C_DA appears in the coefficients. The correction actually should be thought of as applying to not only the whole ballistic parameter but including a correction to the mean density as well. The correlations between any separate determination of these factors would be very high indeed when only satellite position and velocity observations are used.

a. Preliminary Calculations

This part of the program calculates "observations" of the orbit specified by the input set of elements (or subsequently corrected elements) made from the sensor station. Given the station coordinates of latitude, ϕ , east longitude, $\lambda_{\rm E}$, and height above sea level, H, and Greenwich sidereal time, $\theta_{\rm to}$, at satellite epoch, to, the following procedure computes the observations $\rho_{\rm C}$, $\rho_{\rm C}$ and the direction cosines of the unit vector, $\underline{\rm L}$, from the station to the satellite for time, t, in minutes since epoch.

Compute local sidereal time, θ , at time, t:

$$\theta = \lambda_{R} + \theta_{to} + (0.0043752691) t$$
 (idod 2π)

Compute the station vector, \underline{R} :

$$X = \left[\frac{X}{\cos \theta}\right] \cos \theta$$

$$Y = \left[\frac{Y}{\sin \theta} \right] \sin \theta$$

$$z = z$$

Compute the slant range, ρ_{c} :

$$\underline{\rho}_{c} = \underline{r} + \underline{R}$$

$$\rho_{\rm c} = \sqrt{\rho_{\rm x}^2 + \rho_{\rm y}^2 + \rho_{\rm z}^2}$$

$$\rho_{x} = x + X$$

$$\rho_y = y + Y$$

$$\rho_z = z + Z$$

where x, y, z are components of \underline{r} obtained from Section 3.2 by means of input elements and the time, t.

Compute unit vector from the station to the satellite in the equatorial coordinate system:

$$L_{xc} = \frac{\rho_x}{\rho_c}$$

$$L_{yc} = \frac{\rho_y}{\rho_c}$$

$$L_{zc} = \frac{\rho_z}{\rho_c}$$

Compute range rate, $\dot{\rho}_{c}$,

$$\dot{X} = -Y \dot{\theta}, \quad \dot{\theta} = 0.058,834,47$$

$$\dot{\mathbf{x}} = \mathbf{x} \ \dot{\mathbf{\theta}}$$

$$\dot{z} = 0$$

$$\dot{\underline{\rho}}_{c} = \dot{\underline{r}} + \dot{\underline{R}},$$

$$\dot{\rho}_{c} = \underline{L} \quad \dot{\rho}_{c} = \underline{L}_{x} \quad (x + X) + \underline{L}_{y} \quad (y + Y) + \underline{L}_{z}z,$$

where x, y, z are components of \underline{r} , obtained from Section 3.2.

b. Range Observations

If range is observed, the residual is

$$R_1 = \rho - \rho_c$$

c. Angular Observations

If azimuth, A, and elevation, h, are observed, the residuals are, respectively,

$$R_2 = \rho_c \stackrel{\sim}{\underline{A}} \cdot (\underline{L} - \underline{L}_c)$$

$$R_3 = \rho_c \, \frac{\tilde{D}}{\tilde{D}} \cdot (\underline{L} - \underline{L}_c)$$

where

$$\frac{\widetilde{A}}{A} = \widetilde{A}_{xh} \underline{s} + \widetilde{A}_{yh} \underline{e} + \widetilde{A}_{zh} \underline{z}$$

$$\frac{\tilde{D}}{\tilde{D}} = \tilde{\tilde{D}}_{xh} \underline{s} + \tilde{\tilde{D}}_{yh} \underline{E} + \tilde{\tilde{D}}_{zh} \underline{z}$$

$$\underline{L} = L_{xh} \underline{S} + L_{yh} \underline{E} + L_{zh} \underline{Z}$$

The \underline{S} , \underline{E} , \underline{Z} unit vector system and the horizon oriented \underline{L}_h , $\overline{\underline{A}}_h$, $\underline{\underline{D}}_h$ unit vector system are defined by:

$$\underline{S} \left\{ \begin{array}{l} S_x = \sin \phi \cos \theta \\ \\ S_y = \sin \phi \sin \theta \\ \\ S_z = -\cos \phi \end{array} \right.$$

$$\underline{\underline{E}} \begin{cases} \underline{E}_{x} = -\sin \theta \\ \underline{E}_{y} = \cos \theta \\ \underline{E}_{z} = 0 \end{cases}$$

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$$\underline{Z} \begin{cases} Z_{x} = \cos \phi \cos \theta \\ Z_{y} = \cos \phi \sin \theta \\ Z_{z} = \sin \phi \end{cases}$$

$$\underline{L}_{h} \begin{cases} L_{xh} = -\cos A \cos h \\ L_{yh} = \sin A \cos h \\ L_{zh} = \sin h \end{cases}$$

$$\underbrace{\widetilde{A}}_{h} \begin{cases}
\widetilde{A}_{xh} = \sin A \\
\widetilde{A}_{yh} = \cos A \\
\widetilde{A}_{zh} = 0
\end{cases}$$

$$\underbrace{\widetilde{D}}_{h} \left\{ \begin{array}{l} \widetilde{D}_{xh} = \cos A \sin h \\ \widetilde{D}_{yh} = -\sin A \sin h \\ \widetilde{D}_{zh} = \cos h \end{array} \right.$$

If right ascension, α , and declination, δ , are observed, the residuals are:

$$R_4 = \rho_c \underline{A} \cdot (\underline{L} - \underline{L}_c)$$

$$R_5 = \rho_{\underline{C}} \underline{D} \quad (\underline{L} - \underline{L}_{\underline{C}})$$

where

$$\underline{\underline{A}} \begin{cases} A_x = -\sin \alpha \\ A_y = \cos \alpha \\ A_z = 0 \end{cases}$$

$$\underline{D} \left\{ \begin{array}{l} D_{x} = -\sin \delta \cos \alpha \\ \\ D_{y} = -\sin \alpha \sin \delta \\ \\ D_{z} = \cos \delta \end{array} \right.$$

$$\underline{L} \left\{ \begin{array}{l} L = \cos \delta \cos \alpha \\ x = \cos \delta \sin \alpha \\ \\ L_y = \cos \delta \sin \alpha \\ \\ L_z = \sin \delta \end{array} \right.$$

See Figure 4 for these vector relationships.

d. Range Rate Observations

If range rate, $\dot{
ho}$, is observed,

$$R_6 = \rho_c \Delta \dot{\rho} = (\dot{\rho} - \dot{\rho}_c) \rho_c$$

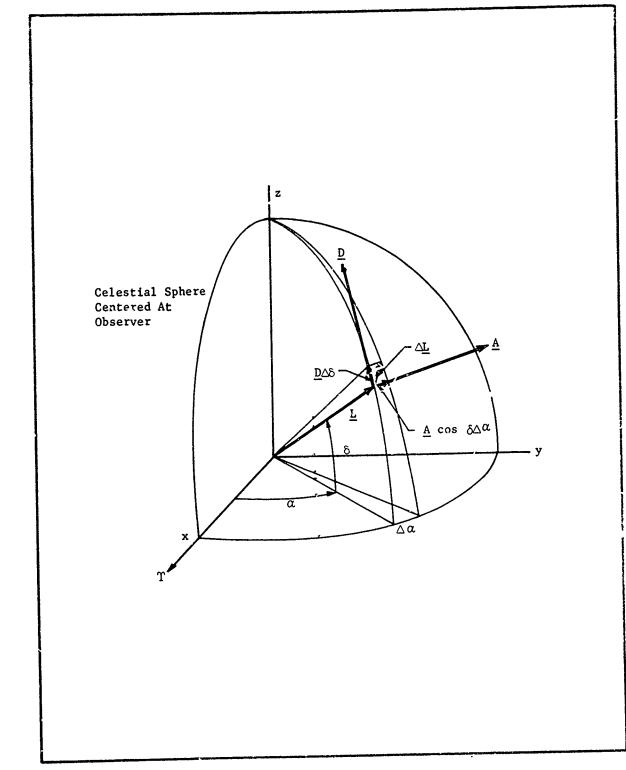


FIG. 4 VECTOR RELATIONSHIPS

e. Differential Correction Solution

The residuals in the observations are related to the changes in the elements through a first order approximation of the form

$$\begin{aligned} R_{i} &= \left(\frac{C_{\Delta n}}{n} \right)_{i}^{\Delta n_{o}} + \left(\frac{C_{\Delta a_{xn}}}{n_{o}} \right)_{i}^{\Delta a_{xn}} + \left(\frac{C_{\Delta a_{yn}}}{n_{o}} \right)_{i}^{\Delta a_{yn}} \Delta a_{yn_{o}} + \left(\frac{C_{\Delta U_{o}}}{n_{o}} \right)_{i}^{\Delta U_{o}} \\ &+ \left(\frac{C_{\Delta \Omega}}{n} \right)_{i}^{\Delta \Omega_{o}} + \left(\frac{C_{\Delta i}}{n_{o}} \right)_{i}^{\Delta i_{o}} + \left(\frac{C_{\Delta i}}{n_{o}} \right)_{i}^{\Delta i_{o}} + \left(\frac{C_{\Delta U_{o}}}{n_{o}} \right)_{i}^{\Delta u_{o}} \end{aligned}$$

where the form o' the coefficients, C_i , depend on the observation type in residual, R_i : time of observation, and the observation weights. These coefficients, which have been developed by means of first-order partials, are functions of the orbit elements and computed observations.

The coefficients are computed by first establishing the R and U coefficients at time $\ensuremath{\text{t}}$.

$$R_{u} = (a^{2}/r) e \sin E$$
 $R_{n} = -2/3 r + (U - U_{o}) R_{u}$
 $R_{xN} = (a^{2}/r) \left[a_{xN} - \cos (E + \omega) \right]$
 $R_{yN} = (a^{2}/r) \left[a_{yN} - \sin (E + \omega) \right]$
 $U_{u} = (a^{2}/r) \sqrt{1 - e^{2}}$
 $U_{n} = (U - U_{o}) U_{n}$

$$U_{xN} = \frac{a^{2}}{r} \left\{ (1 + \frac{r}{a}) \sin (E + \omega) + \frac{a_{xN} e \sin E}{\left[\frac{e^{2} - (1 + \sqrt{1 - e^{2}}) e \cos E}{(1 + \sqrt{1 - e^{2}})^{2} \sqrt{1 - e^{2}}} \right] - \frac{a_{yN}}{1 + \sqrt{1 - e^{2}}} \right\}$$

$$U_{yN} = \frac{a^{2}}{r} \left\{ - (1 + \frac{r}{a}) \cos (E + \omega) + \frac{a_{yN} e \sin E}{(1 + \sqrt{1 - e^{2}})^{2} \sqrt{1 - e^{2}}} \right\} + \frac{a_{xN}}{1 + \sqrt{1 - e^{2}}} \right\}$$

When the plant range is observed, the residual and coefficients are given by the expressions:

$$\begin{split} R &= \frac{R_1}{\sigma_\rho} \\ C_{\underline{\Delta n}} &= \left[\underline{L}_c \cdot \underline{U} \ R_n + \underline{L}_c \cdot \underline{V} \ \underline{U}_n \right] \frac{1}{\sigma_\rho} \\ C_{\Delta a_{xN}} &= \left[\underline{L}_c \cdot \underline{U} \ R_{xN} + \underline{L}_c \cdot \underline{V} \ \underline{U}_{xN} \right] \frac{1}{\sigma_\rho} \\ C_{\Delta a_{yN}} &= \left[\underline{L}_c \cdot \underline{U} \ R_{yN} + \underline{L}_c \cdot \underline{V} \ \underline{U}_{yN} \right] \frac{1}{\sigma_\rho} \\ C_{\Delta u_{o}} &= \left[\underline{L}_c \cdot \underline{U} \ R_u + \underline{L}_c \cdot \underline{V} \ \underline{U}_u \right] \frac{1}{\sigma_\rho} \\ C_{\Delta \Omega} &= \left[\underline{L}_c \cdot \underline{V} \ r \ cos \ i - \underline{L}_c \cdot \underline{W} \ r \ sin \ i \ cos \ u \right] \frac{1}{\sigma_\rho} \\ C_{\Delta \hat{l}} &= \left[\underline{L}_c \cdot \underline{W} \ r \ sin \ u \right] \frac{1}{\sigma_\rho} \\ C_{\Delta \hat{l}} &= \left[\underline{L}_c \cdot \underline{W} \ r \ sin \ u \right] \frac{1}{\sigma_\rho} \end{split}$$
 where the v subscript refers to

the range computed from the variant ephemeris. If computed by the analytic formula,

$$C_{\Delta \frac{1}{m}} = \left[\frac{2}{3} \text{ a n (t - t_o) } C_{D} \text{ Ap}_{r} C_{\underline{\Delta n}} \text{ K} \right] \frac{1}{\sigma_{\rho}}$$

where K is a unit conversion constant and C_D is set equal to 2. The quantity σ_ρ in the coefficient equations is the standard deviation in the range measurement, so that $\frac{1}{\sigma_\rho}$ is the weight of that measurement, assigned as described by Section 3.1.

When azimuth A is observed, then $R = \frac{R_2}{\sigma_A}$ and the coefficients are obtained by replacing \underline{L} by \underline{A} . In this case, the $\frac{1}{\sigma_C}$ is replaced by $\frac{1}{\rho_C}\frac{\sigma_C}{\sigma_A}$ where $\frac{\sigma_C}{\sigma_A}$ is the standard deviation in the azimuth measurement. The seventh coefficient, in the variant ephemeris mode, must be computed as

$$c_{\Delta \frac{1}{m}} = \frac{1}{\rho_{c} \sigma_{A}} \left[\frac{\rho_{c} \underline{A} \cdot (\underline{L}_{v} - \underline{L}_{c})}{\delta (\frac{1}{m})} \right]$$

With the azimuth, elevation h is always observed, and in this case $R = \frac{R_3}{\sigma_h} \text{ and the corresponding coefficients are obtained by replacing } \underline{L}$ with \underline{D} . $\frac{1}{\sigma_\rho}$ is replaced by $\frac{1}{\rho - \sigma_h}$, where σ_h is the standard deviation in the elevation measurement. The seventh coefficient in the variant ephemeris mode is

$$c_{\Delta \frac{1}{m}} = \frac{1}{\rho_c \sigma_h} \left[\frac{\rho_c \tilde{\underline{\underline{\underline{L}}}} \cdot (\underline{\underline{\underline{L}}}_v - \underline{\underline{\underline{L}}}_c)}{\delta (\frac{1}{m})} \right]$$

If right ascension α is observed, then $R=\frac{\kappa_4}{\sigma_\alpha}$ and the corresponding coefficients are obtained by replacing \underline{L} with \underline{A} . $\frac{1}{\sigma_\rho}$ is replaced by $\frac{1}{\rho - \sigma_\alpha}$, where σ_α is the standard deviation in the right ascension. The seventh coefficient in the variant ephemeris mode is

$$C_{\Delta_{\overline{m}}} = \frac{1}{\rho_{c} \sigma_{\alpha}} \left[\frac{\rho_{c} \underline{A} \cdot (\underline{L}_{v} - \underline{L}_{c})}{\delta (\frac{1}{m})} \right]$$

Along with right ascension, declination δ is always observed, and in this case $R=\frac{R_5}{\sigma_\delta}$ and the corresponding coefficients are obtained by replacing \underline{L}_c with \underline{D} . $\frac{1}{\sigma_\rho}$ is replaced by $\frac{1}{\rho_c \sigma_\delta}$, where σ_δ is the standard deviation in the declination. The seventh coefficient in the variant ephemeris mode is

$$C_{\Delta \frac{1}{m}} = \frac{1}{\rho_{c} \sigma_{\delta}} \left[\frac{\rho_{c} \underline{D} \cdot (\underline{L}_{v} - \underline{L}_{c})}{\delta (\frac{1}{m})} \right]$$

If range rate, $\stackrel{\cdot}{\rho}$, is observed, the preliminary coefficients are computed from:

$$\dot{R}_{u} = \sqrt{\mu} \frac{a^{5/2}}{r^3} (e \cos E - e^2)$$

$$\dot{R}_n = \frac{\dot{r}}{3} + (U - U_o) \dot{R}_u$$

$$\dot{R}_{xN} = \sqrt{\mu} \frac{a^{5/2}}{r^3} [\sin (E + \omega) - a_{xN} e \sin E - a_{yN}]$$

$$\dot{R}_{yN} = \sqrt{\mu} \frac{a^{5/2}}{r^3} \left[-\cos (E + \omega) - a_{yN} e \sin E + a_{xN} \right]$$

$$\dot{U}_{u} = -\sqrt{\mu} \frac{a^{5/2}}{r^3} \sqrt{1 - e^2} e \sin E$$

$$\dot{U}_{n} = \frac{r\dot{v}}{3} + (U - U_{o}) \dot{U}_{u}$$

$$\dot{U}_{xN} = \sqrt{\mu} \frac{a^{5/2}}{r^3} \sqrt{1 - e^2} \left[\cos (E + \omega) - a_{xN} \left(1 + \frac{r^2}{ap} \right) \right]$$

$$\dot{U}_{yN} = \sqrt{\mu} \frac{a^{5/2}}{r^3} \sqrt{1 - e^2} \left[\sin (E + \omega) - a_{yN} \left(1 + \frac{r^2}{ap} \right) \right]$$
The range rate coefficients are then computed as
$$\dot{U}_{xN} = \frac{1}{2} \left[\frac{1}{2} \left[\frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \frac{1}{2} \frac{1}{2} + \frac{1}{2} \frac{1}{2} \frac{1}{2} + \frac{1}{2} \frac{1}{2$$

$$\begin{split} \mathbf{C}_{\underbrace{\Delta \, \mathbf{n}}} &= \left\{ \begin{array}{l} \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{U}} \, \left[\, \dot{\rho}_{c} \, \left(\dot{\mathbf{R}}_{n} - \dot{\mathbf{v}} \mathbf{U}_{n} \right) - \dot{\rho}_{c} \, \mathbf{R}_{n} \, \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{U}} \, \mathbf{R}_{n} \\ &+ \, \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{V}} \, \left[\, \dot{\rho}_{c} \, \left(\dot{\mathbf{U}}_{n} + \frac{\dot{\mathbf{r}}}{r} \, \mathbf{U}_{n} \right) - \dot{\rho}_{c} \, \mathbf{U}_{n} \, \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{U}_{n} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \\ \mathbf{C}_{\Delta \mathbf{a}} &= \left\{ \begin{array}{l} \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{U}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{R}}_{xN} - \dot{\mathbf{V}} \, \mathbf{U}_{xN} \right) - \dot{\rho}_{c} \, \mathbf{R}_{xN} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{U}} \, \mathbf{R}_{xN} \\ &+ \, \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{V}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{U}}_{xN} + \frac{\dot{\mathbf{r}}}{r} \, \mathbf{U}_{xN} - \, \dot{\rho}_{c} \, \mathbf{U}_{xN} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{U}_{xN} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \\ \mathbf{C}_{\Delta \mathbf{a}}_{yN} &= \left\{ \begin{array}{l} \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{U}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{R}}_{yN} - \dot{\mathbf{V}} \, \mathbf{U}_{yN} - \, \dot{\rho}_{c} \, \mathbf{R}_{yN} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{V}_{yN} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \\ + \, \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{V}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{U}}_{yN} + \frac{\dot{\mathbf{r}}}{r} \, \mathbf{U}_{yN} \right) - \, \dot{\rho}_{c} \, \mathbf{R}_{yN} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{V}_{yN} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \\ \mathbf{C}_{\Delta \mathbf{U}_{o}} &= \left\{ \begin{array}{l} \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{U}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{R}}_{u} - \dot{\mathbf{V}} \, \mathbf{U}_{u} \right) - \, \dot{\rho}_{c} \, \mathbf{R}_{u} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{U}_{yN} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \\ + \, \underline{\mathbf{L}}_{c} \bullet \, \underline{\mathbf{U}} \, \left[\, \rho_{c} \, \left(\dot{\mathbf{R}}_{u} - \dot{\mathbf{V}} \, \mathbf{U}_{u} \right) - \, \dot{\rho}_{c} \, \mathbf{R}_{u} \right] + \, \dot{\underline{\rho}}_{c} \bullet \, \underline{\mathbf{V}} \, \mathbf{U}_{u} \, \right\} \frac{1}{\sigma_{\rho}^{2}} \end{array}$$

$$\begin{split} \mathbf{C}_{\Delta\Omega} &= \left\{ - \rho_{\mathbf{c}} \, \, \underline{\mathbf{L}}_{\mathbf{c}} \cdot \underline{\mathbf{U}} \, \, \mathbf{r} \, \, \mathbf{\hat{v}} \, \cos \, \mathbf{i} + \underline{\mathbf{L}}_{\mathbf{c}} \cdot \underline{\mathbf{V}} \, \cos \, \mathbf{i} \, [\, \rho_{\mathbf{c}} \, \, \dot{\mathbf{r}} \, - \, \dot{\rho}_{\mathbf{c}} \, \, \mathbf{r} \, \,] \right. \\ &\quad + \, \frac{\dot{\rho}}{\mathbf{c}} \cdot \underline{\mathbf{V}} \, \mathbf{r} \, \cos \, \mathbf{i} + \underline{\mathbf{L}}_{\mathbf{c}} \cdot \underline{\mathbf{W}} \, \sin \, \mathbf{i} \, [\rho_{\mathbf{c}} \, (\mathbf{r} \, \, \dot{\mathbf{v}} \, \sin \, \mathbf{u} \, - \, \dot{\mathbf{r}} \, \cos \, \mathbf{u} \, \\ &\quad + \, \dot{\rho}_{\mathbf{c}} \, \mathbf{r} \, \cos \, \mathbf{u} \,] \, - \, \dot{\underline{\rho}}_{\mathbf{c}} \cdot \underline{\mathbf{W}} \, \mathbf{r} \, \sin \, \mathbf{i} \, \cos \, \mathbf{u} \, \Big\} \, \frac{1}{\sigma \dot{\rho}} \\ \mathbf{C}_{\Delta\mathbf{i}} &= \left\{ \frac{\underline{\mathbf{L}}_{\mathbf{c}} \cdot \underline{\mathbf{W}} \, [\rho_{\mathbf{c}} \, (\mathbf{r} \, \, \dot{\mathbf{v}} \, \cos \, \mathbf{u} \, + \, \mathbf{r} \, \sin \, \mathbf{u}) \, - \, \dot{\rho}_{\mathbf{c}} \, \mathbf{r} \, \sin \, \mathbf{u} \, \Big\} \, \frac{1}{\sigma \dot{\rho}} \\ \mathbf{C}_{\Delta\mathbf{i}} &= \left\{ \frac{\rho_{\mathbf{c}} \, (\dot{\rho}_{\mathbf{v}} - \dot{\rho}_{\mathbf{c}})}{\delta \, (\frac{1}{\mathbf{m}})} \right\} \frac{1}{\sigma \dot{\rho}} \end{split}$$

If computed by the analytic formula,

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$$c_{\Delta \frac{1}{m}} = \left[\frac{2}{3} \text{ an } (t - t_{o}) \quad C_{D} \quad A \quad \rho_{r} \quad C_{\Delta n} \quad K\right] \frac{1}{\sigma_{\rho}^{*}}$$

$$\sum_{j=1}^{N} c_{ij} \quad \Delta_{j} = R_{ij}$$
Let

represent all such equations of condition, where C_{ij} are the coefficients, R_{ij} are the accepted observation residuals, Δ_{ij} are the corrections to the orbital elements, and N is the number of elements to be corrected and is the number of accepted observation residuals. The resulting matrix equation is solved to give the corrections, Δ_{ij} in a least square sense, to the orbital elements at time, t. These corrections are applied as follows (primes denote corrected elements):

$$n_{c}^{\prime} = n_{o} \left(1 + \frac{\Delta n_{o}}{n_{o}}\right)$$

$$U_{o}^{\prime} = U_{o} + \Delta U_{o}$$

$$a'_{xNo} = a_{xN_o} + \Delta a_{xN}$$

$$a'_{yNo} = a_{yNo} + \Delta a_{yN}$$

$$\Omega'_{o} = \Omega_{o} + \Delta \Omega$$

$$i'_{o} = i_{o} + \Delta i$$

$$L'_{o} = U'_{o} + \Omega'_{o} \text{ if } W'_{z} = \cos i \ge 0$$

$$L'_{o} = U'_{o} - \Omega'_{o} \text{ if } W'_{z} = \cos i < 0$$

Following the above calculation of the corrected elements, another representation of the observations is performed, on the basis of the corrected elements, and another set of residuals is formed by using the same input observations. The RMS values of the last two sets of consecutive residuals are compared to insure convergence of the computational process. The process is complete when the residual RMS converges to the minimum value considered as acceptable.

3.4 PREDICTION AND RELIABILITY

Once a corrected set of elements has been established, the Special Perturbations formulation is used to compute future position and velocity. The accuracy of the prediction may be estimated by means of an analysis of the effect of the element uncertainties by their propagation through the representation equations.

a. Prediction Options

The prediction function applies the equations of Section 3.2 to represent the position and velocity at some specified time. Two modes of prediction have been formulated: (1) prediction by specifying the initial time, the number of points and some time interval and (2) prediction for the time of closest approach to some specified sensor.

Prediction by time is a process of representing the position and velocity at the requested times. In the Special Perturbations formulation this requires an integratior to the initial time point followed by integration to the subsequent time points, as specified by the time interval, until the final time is reached.

Prediction by sensor requires a more complex logic. Here, the numerical integration proceeds until the range rate relative to the station changes sign from negative to positive. At this point, the integration is used as part of an iterative scheme to obtain the time when range rate is zero. Once established, this is considered to be the time of closest approach. The routine then goes on to obtain prediction points for specified time intervals and duration on either side of the time of closest approach. This process may be repeated for any number of passes over the sensor; however, it is restricted to one sensor.

b. Reliability Estimates

The prediction function has the capability of estimating the reliability of its prediction points. This estimate is obtained by means of the variance-covariance matrix of orbit elements established in the final iteration in the differential correction process (Section 3.3 e). This matrix may be a six by six or a seven by seven depending on the nature of the differential correction. In either case the variance-covariance matrix may be defined as $\left[A^{-1}\right]$, and the quadratic form

$$[D] = [G] [A^{-1}] [G]^{T}$$

leads to the variance-covariance matrix of predicted position [D].

The variance-covariance matrix of predicted velocity $\left[\,\dot{D}\,\right]$ is obtained from the quadratic form

$$[\check{\mathbf{D}}] = [H] [A^{-1}] [H]^{\mathrm{T}}$$

The formulation for the standard deviation in predicted position and predicted velocity requires the formation of the [G] and [H] matrices. The [G] matrix is used to relate uncertainties in orbital elements to uncertainties in predicted position. The [H] matrix is used to relate uncertainties in orbital elements to uncertainties in predicted velocity.

The [G] matrix is composed of the following matrix elements:

$$g_{11} = R_n$$

$$g_{12} = R_{xn}$$

$$g_{13} = R_{yn}$$

$$g_{14} = R_u$$

$$g_{15} = 0$$

$$g_{16} = 0$$

$$g_{17} = 2/3 \text{ an(t-t}_0) C_D A \rho_r R_n$$

$$g_{21} = U_n$$

$$g_{22} = U_{xn}$$

$$g_{23} = U_{yn}$$

$$g_{24} = v_u$$

$$g_{26} = 0$$

$$g_{27} = 2/3 \text{ an}(t-t_0) C_D A P_r U_r$$

$$g_{31} = 0$$

$$g_{32} = 0$$

$$g_{33} = 0$$

$$g_{34} = 0$$

$$g_{35} = -r \sin i \cos u$$

$$g_{36} = r \sin u$$

$$g_{37} = 0$$

The [H] matrix is composed of the following matrix elements:

$$h_{11} = (\dot{R}_n - \dot{v} U_n)$$

$$h_{12} = R_{xn} - v U_{xn}$$

$$h_{13} = \dot{R}_{yn} - \dot{v} U_{yn}$$

$$h_{14} = \dot{R}_u - \dot{v} U_u$$

$$h_{16} = 0$$

$$h_{17} = 2/3 \text{ an(t-t_o)} C_D A \rho_r (\dot{R}_n - \dot{v}U_n)$$

$$h_{21} = \dot{v}_n + \frac{\dot{r}}{r} v_n$$

1

Server.

$$h_{22} = \dot{v}_{xn} + \frac{\dot{x}}{r} v_{xn}$$

$$h_{23} = \dot{v}_{yn} + \frac{\dot{r}}{r} v_{yn}$$

$$h_{24} = \dot{U}_u + \frac{\dot{r}}{r} U_u = 0$$

$$h_{25} = \dot{r} \cos i$$

$$h_{26} = 0$$

$$h_{27} = 2/3 \text{ an(t-t_o) } C_D \land \rho_r (\dot{v}_n + \frac{\dot{r}}{r} v_n)$$

$$h_{31} = 0$$

$$h_{32} = 0$$

$$h_{33} = 0$$

$$h_{3/4} = 0$$

$$n_{35} = (r\dot{v} \sin u - \dot{r} \cos u) \sin i$$

$$h_{36} = r\dot{v} \cos u + \dot{r} \sin u$$

$$h_{37} = 0$$

The quantities R_n , R_{xn} , R_{yn} , R_u , U_n , U_{xn} , U_{yn} , U_u , \dot{R}_n , \dot{k}_{xn} , \dot{k}_{yn} , \dot{R}_u , \dot{U}_u , \dot{U}_{xn} , \dot{U}_{yn} , \dot{U}_u are defined in Section 3.3 e.

The matrices [G] and [H] are functions of the orbit parameter and the prediction time. $[G]^T$ and $[H]^T$ are the matrix transpose of [G] and [H], respectively.

Thus, the reliability estimates are obtained from the main diagonals of [D] and $[\dot{D}]$. These estimates are the standard deviations of the in-track, cross-track, and out-of-plane components of position and velocity at the prediction time.

SECTION 4

OPERATING INSTRUCTIONS

The Executive Program of the SPS B-2 System processes the Element, Sensor, Observation and Parameter cards leaving the data in specified B-2 core buffer locations to be accessed by OBSWGT and SPWDC.

The Observation Weighting Program will reformat the observations, ordering them in time and applying weights (optional) for a maximum of 400 observations. It then calls SPWDC for execution.

The SPWDC program may go through a differential correction process, prediction by station, or prediction by time as specified on the Program Parameter Cards.

4.1 TAPE SETUP

The logical tape assignments are:

Logical Unit	Tape Description
1	SPS B-2 Binary Master
2	Input
4	SEAI
6	SRADU (optional observation input)
7	Weight tape (optional)
11	Output
12	r, r binary output tape (optional)

4.2 DECK SETUP

Input to the SPWDC Program consists of SPS control cards, Parameter cards, Element cards, Sensor cards and Observation cards (Figure 5).

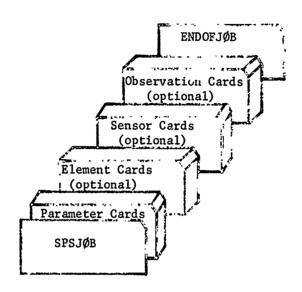


FIGURE 5. SPWDC INPUT DECK

4.3 INPUT

a. Program Notes

- (1) The input options for the SPSJOB card are to be found in Appendix I.
- (2) The differential correction is controlled by the following cards:
 - (a) The OBSWGT Parameter card calls the SPWDC Program.
 - (b) The Vehicle Characteristic card contains the mass, diameter, and reflectivity of the satellite for

the drag and radiation pressure computations. This card may be omitted if the following values are acceptable:

mass = 10.0 kg

diameter = 1.0 meter

reflectivity = 1.0

- (c) The Differential Correction Control card contains the pertinent information for the integration and differential correction.
- (d) The Absolute Error Control card may be omitted if

$$a_{L} = 10^{-7}$$

$$a_{\underline{a}}, a_{\underline{h}} = 10^{-8}$$

are acceptable values.

(e) The Relative Error Control card may be omitted if

$$r_L$$
, $r_{\underline{a}}$, $r_{\underline{h}} = 0$

are acceptable values.

- (f) The Program Execution card specifies that a differential correction is to be executed and starts operation of the program.
- (3) Prediction by time is controlled by the following cards:
 - (a) OBSWGT Control card
 - (b) Absolute Error Control card
 - (c) Relative Error Control card
 - (d) Time Prediction card #1. (This card contains integration and output information.)

- (e) Time Prediction card #2. (The time output interval is indicated on this card.)
- (f) Program Execution card. (The Prediction-by-time path is set, and execution begins.)
- (4) Prediction-by-station is controlled by these cards:
 - (a) OBSWGT Parameter card
 - (b) Absolute Error Control card
 - (c) Relative Error Control card
 - (d) Station Pass Prediction card #1. (The integration and output information is specified.)
 - (e) Station Pass Prediction card #2. (Sensor data may be input from this card or from a B-2 SEAI tape.)
 - (f) Program Execution card. (The Prediction-by-sensor path is set, and execution begins.)
- (5) Each of the three, differential correction, predictionby-station, or prediction-by-time, may be run separately, or the combination of differential correction and prediction-by-station or time may be executed. For actual test cases and variations of logical paths, see Section 6.

b. Input Deck

A typical input deck is arranged as follows:

70 SCHTP $(^{11}8_2)$

JOB Card

REM Card

SPSJOB

Parameter Cards

Element Cards (SPADATS format) (3)

Sensor Cards (SPADATS format) (3)

Observation Cards (SPADATS format) (3)

ENDOFJOB $(^{11}8_2)$ ENDSCHED $(^{11}8_2)$

Since the Element, Sensor and Observation cards are standard SPADATS System cards, only the Program Parameter cards and the Weighting Tape Input will be described in this Section.

(1) Parameter Card Formats

The first parameter card must be the OBSWGT card which contains the identity of the program called by OBSWGT after processing the observations. The rest of the parameter cards may be in any order, with the exception of the Program Execution card which must be the last card. Note that:

- (a) If six or seven elements are being corrected, the n only correction and the Δq check may be chosen as options. (Differential Correction Control card)
- (b) The prediction reliance option for predictionby-time or station is only possible if six or seven elements are to be differentially corrected, the observations are weighted, and the drag perturbation is computed (for correction of seven elements). If these conditions are not met, the flag is turned off and the run proceeds without prediction reliance. (Time and Station Prediction cards)

 $\label{lem:appendix I} \textbf{Appendix I contains the Parameter card formats and related code information.}$

(2) Weighting Cards

Additional weighting input data may be contained on a weighting tape which has the following card deck setup:

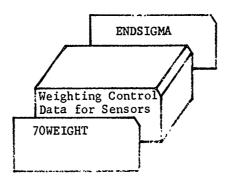


FIGURE 6. CARD DECK FORMAT FOR THE WEIGHTING TAPE

Data will consist of the standard deviations (1) for the observations specified as constants for each sensor, (2) for each observation, or (3) specified by control information for determining the method to be used for computing the standard deviation.

There may be weighting of all observations or no weighting, but in a particular job there cannot be both weighted and unweighted observations. There must be sigmas for all quantities observed or the observation will be rejected for lack of weighting information. Weighting information is obtained from Weight tape or from the file data in the Observation Weighting Program. (Appendix I contains the card formats for the Weighting tape.)

A weighting tape must contain weighting information for (1) sensors only, (2) observations only, (3) functions only, or (4) sensors and functions.

4.4 OUTPUT

The output for SPWDC consists of element cards, printed data, and optionally a binary tape and/or punched cards. The SPADATS seven element cards plus the vehicle characteristic card are punched out (data select 2, code mode) after the successful completion of the differential correction of the orbit. A binary tape containing time in minutes since epoch, position (\underline{r}) and velocity (\dot{r}) is an optional output for prediction. See Figure 7.

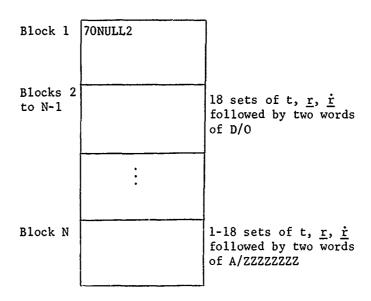


FIGURE 7. CONTENTS OF BINARY TAPE

The printed data (data select 1) consist of heading lines, differential correction output, prediction output and error comments. An additional punched card option will output special format cards containing time and position data. The punched cards contain \underline{r} and integral days since beginning of the year (first card) and fractional time (second card) in the format

ID + XXXXXXXXX + YY

where ID is an identifier: ID 08 X 09 Y 10 2 11 t (integral days since beginning of year) 12 t (fractional day) a. Initial Output The first line of each page will be: SPECIAL PERTURBATIONS WITH WEIGHTED DIFFERENTIAL CORRECTION PRG (Date) PAGE This is followed by the card image of the parameter cards. Any error on an input parameter card will cause the following comment to be printed: ERROR IN INPUT CARD NO JOB TERMINATED If the proper sensor data was not found on the SEAI tape or on a sensor card, the remark NO COORDINATES FOR STATION NO_____, OBS. SKIPPED is printed. When no standard deviations are found for an observation, NO WEIGHTING INFORMATION FOR OBS. FROM STATION NO , OBS. SKIPPED is printed.

b. <u>Differential Correction Output</u>

The differential correction output consists of the residuals (optionally) for all of the observations, followed by the root-mean-squares, correction to the elements and corrected elements. For a weighted run the normalized root-mean-squares are also output. This output is repeated until the differential correction converges or diverges.

3	For convergence the final set of residuals is followed by the comment
	DC CONVERGED - THE NEXT CORRECTIONS WOULD BE
ŧ.	and the final set of corrections. This is followed by
	NO. OF RESIDUALS USED =NO. OF RESIDUALS REJECTED =
ľ	printed with the values. Then follows
ž	OLD ELEMENTS WITH RESPECT TO OLD EPOCH
	OLD ELEMENTS WITH RESPECT TO INTERMEDIATE EPOCH
	NEW ELEMENTS WITH RESPECT TO INTERMEDIATE EPOCH
	NEW ELEMENTS WITH RESPECT TO NEW EPOCH
ŧ ; •	with appropriate values. The seven element cards and the vehicle characteristic card are punched out when the differential correction has converged. Following this output, the comment
, - 	ELEMENT SET UPDATED
	is printed. For divergence, the error comment
*	DIFFERENTIAL CORRECTION DID NOT CONVERGE, JOB TERMINATED
	is followed by the proposed corrections to the elements and the corrected elements with respect to the old epoch.
	c. Prediction Output
	For prediction by print triples there are four output options. The time in days since beginning of the year is followed by any or all of the
.	following: (1) position and velocity $(\underline{r}, \dot{\underline{r}})$
	(2) osculating orbital elements (a, e, i, Ω , ω , U)
יים	(3) subsatellite track (\emptyset , $\lambda_{\rm E}$, h)

For prediction by station pass there is, in addition, the option to output

(4) acquisition coordinates ($\rho, \dot{\rho}$, A, h)

d. Prediction Reliability Output

The optional prediction reliability output will print the standard deviation in the predicted position and velocity components at each prediction point. The format provides two lines of data per time point. On the first line the standard deviations are referred to the cross-track, in-track and out-of-plane coordinates, and on the second line they are referred to the inertial x, y, z coordinate system.

e. Error Comments

The following are error comments which may appear on the printed output:

(1) An error in the Runge-Kutta integration routine will give one of the following comments:

ERROR IN INTEGRATING VARIANT EPHEMERIS, JOB TERMINATED. (Correcting Mass)

ERROR IN INTEGRATING EPHEMERIS FOR DC, JOB TERMINATED. (No Mass Correction)

ERROR IN RUNGE-KUTTA IN PREDICTION BY TIME RUN TERMINATED. (Predict.on by Time)

A(I) + R(I)Y(I)=0 ERROR IN RUNGE KUTTA INTEGRATION (Prediction by Station)

DELTA T = 0 AT ANY PT IN THE INTEGRATION PROCESS (Prediction by Station)

(2) In computing the satellite altitude for the drag perturbation for too-low a satellite, this comment is printed:

> SATELLITE DROPPED BELOW 50 KMS. TIME SINCE EPOCH = MIN.

(3) When all the observations are rejected before the differential correction,

NO GOOD OBSERVATIONS END OF JOB

is printed.

(4) If Kepler's equation could not be solved for $(E + \omega)$ before entering the integration routine, the comment

DID NOT CONVERGE IN KELLERS EQN IN 50 ITERATIONS, RUN TERMINATED

appears on the output.

(5) If the number of good observations was less than the number of elements to be corrected,

DC FAILED. NOT ENOUGH GOOD OBSERVED QUANTITIES TO SOLVE THE LEAST SQUARES MATRIX, JOB TERMINATED

is printed.

(6) If the RMS gets larger twice in a row, if there is a change greater than 0.5% in the RMS, or if the maximum number of passes through the differential correction have been made, the following is printed:

DIFFERENTIAL CORRECTION DID NOT CONVERGE, JOB TERMINATED.

(7) When the input $\triangle q$ is greater than the computed $\triangle q$, this comment appears:

DELTA Q TOO LARGE, REPEAT CORRECTION WITHOUT CORRECTION AXN AND AYN.

(8) When the prediction reliability check is attempted in a correction involving less than six elements, this comment appears:

INSUFFICIENT EQUATIONS TO OUTPUT SIGMAS

SECTION 5

FLOW DIAGRAMS

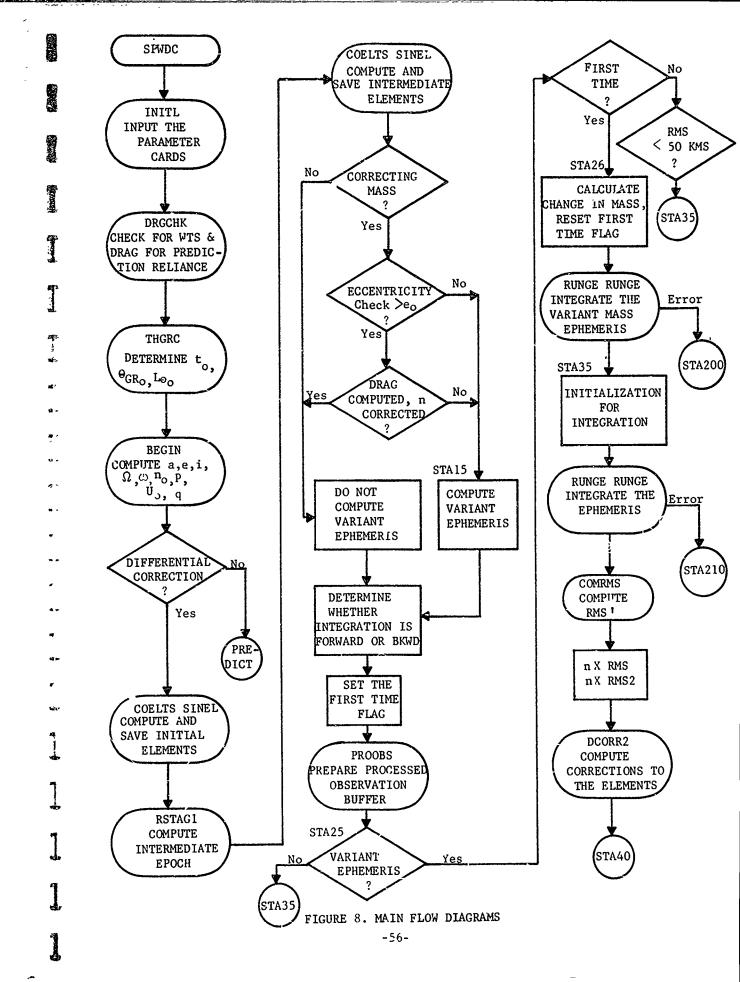
The following flow diagrams display the computational procedures and logical flow used in the program. Standardized symbols are maintained throughout. Ovals are used to indicate subroutines. Rectangles are used for computational processes. Diamonds represent logical decisions or branching tests.

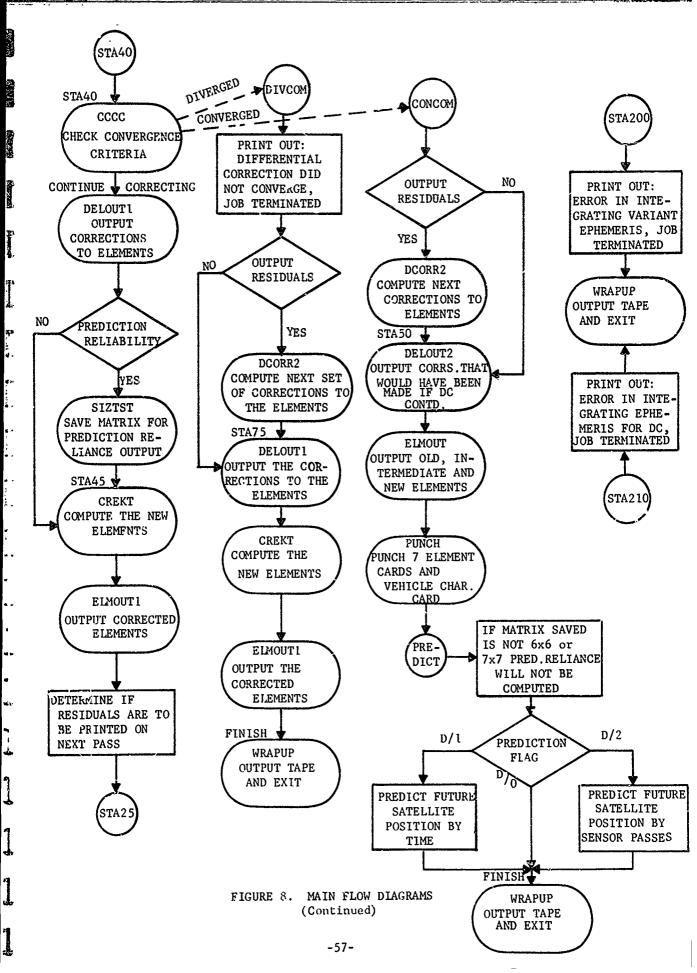
5.1 MAIN FLOW DIAGRAMS

The main flow of the program is shown in macro structure on the following two pages. These diagrams display the differential correction function and the prediction function of SPWDC.

5.2 DETAILED FLOW DIAGRAMS

The detailed flow diagrams are displayed in Appendix II and show all program loops within SPWDC.





SECTION 6

COMPILED TEST CASES

The three test cases for Satellite 116 described in this section will test the logical paths of the program. Note that the Observation and Element cards are the same for all cases and the sensors are obtained from the SEAI tape. The vehicle characteristics for 61 OMICRON 1 are diameter 1.1283 $_{\rm HI}$, and mass 79.378 kg.

6.1 TEST CASE 1

See Figure 9, Weighted Differential Correction.

The first test case is a weighted differential correction with 11 observations covering a 40-hour period. The element set and observations are card inputs to the program; the sensors are obtained from the SEAI tape (input option 5). The weighting data are from the Weight Tape (Figure 15). Bulge, drag, and radiation pressure perturbations are included in the variable integration with a starting step size of -1.0 minute. Six elements are to be corrected in a maximum of 9 passes through the differential correction with an n only correction on the first pass.

The absolute maximums for rejection are 1000 km and 0.5 km/sec; the rms multiplier is 1.5. All residuals are to be output, and the new epoch is the 10030 revolution.

See Figure 10 for Test Case 1 output.

6.2 TEST CASE 2

See Figure 11, Weighted Differential Correction and Prediction by Time.

The ephemeris calculation incorporates a variable negative integration with an initial step size of one minute taking into account bulge and drag perturbations and taking the new epoch to be 200.7 days since the beginning of the year. Six elements are to be corrected with an n only correction on the first pass and a Δq check of 500 km. The time prediction integration is in the variable mode with an initial step size of 1.0 minute taking into account bulge and drag perturbations. Ten points are output at a one-minute interval starting at 200.7 days (July 19, 1963). All printed options including prediction reliance values are output as well as the binary tape and punched cards.

See Figure 12 for Test Case 2 output.

6.3 TEST CASE 3

See Figure 13, Unweighted Differential Correction and Prediction by Station.

This is an unweighted differential correction run updating the spoch to the time of the last observation. The integration is in the variable mode with an initial step size of -1.0 minute; bulge and drag perturbations are included. Six elements are differentially corrected with an n only correction on the first pass. The initial rejection maximums are 1000 km and 0.5 km/sec with an rms multiplier of 1.5. There is a maximum of nine passes through the differential correction with the residuals output each time.

In the station prediction the integration mode is variable with a two-minute step size; the Earth's bulge and drag are included. Printed output consists of t; \underline{r} , $\underline{\dot{r}}$; ϵ , e, i, Ω , ω , U; \emptyset , $\lambda_{\underline{r}}$, h; and ρ , $\dot{\rho}$, A, h for sensor 216 (coordinates are on the SEAI tape). The output points will be 5 minutes on either side of the point of closest approach at a 1.0 minute interval provided h >1.0°.

See Figure 14 for Test Case 3 output.

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FIGURE 9. WFIGHTED DIFFERENTIAL CORRECTION, TEST CASE 1

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FIGURE 11. WEIGHTED DIFFERENTIAL CORRECTION AND PREDICTION BY TIME, TEST CASE 2

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FIGURE 13. UNWEIGHTED DIFFERENTIAL CORRECTION AND PREDICTION BY STATION, TEST CASE 3

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FIGURE 15. WEIGHT TAPE

APPENDIX I

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PROGRAM PARAMETER CARDS

Code	Contents
1	Alphanumeric information
2	Integers
3	Floating point numbers
	XXX.XXX (decimal anywhere in the field)
	±.XXXX+YY XXXXXXX (no decimal)
4	Flag
	△ or 0: not to be computed 1: to be computed

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Field	Column	Contents
1	1 - 8	SPSJOB
2	9 - 16	OBSWGTE △
3	17	INPUT OPTIONS (See following page)
4	18	O OUTPUT OPTION

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FIGURE 16. SPSJOB CARD

SCHEDULE TAPE INPUT OPTIONS

(Reference SPSJØB Cards)

Option	Sensor Cards	Element Cards	Observation Cards	Parameter Cards	Satellite Cards
0.	Ŋ	N	И*	Y	Y
1	N	Y	И*	Y	N
2	Y	N	.N *	Y	Y
3	Y	Y	N ★	Y	N
4	N	N	Y	Y	Y
5	N	Y	Y	Y	N
6	Y	N	Y	' Y	Y
7	Y	Y	Y	Y	N
8	N	Y	N	Y	N
9	N	N	N	Y	Y

N = No

Y = Yes

1

Options 0-7 refer to differential correction and (optionally) prediction 8-9 refer to prediction only

*Observations are from the SRADU tape.

NOTE: Whenever N appears, data are obtained from data files (except for satellite number cards). In the case of sensors and elements, the data source is the SPS B-2 SEAI tape. When elements are input from the SEAI tape, the Schedule Tape input must contain satellite number cards. If observation cards are not input from the schedule tape, they are obtained from the SRADU tape.

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Field	Column	Contents
1	1 - 8	SPWDC $\Delta\Delta\Delta$
2	9 - 11	Satellite Number (optional)
3	12	0 or △ - Weighting Tape Input 1 - Use Sensor Weighting Data in OBSWGT Weight File
4	13 - 78	Not used
5	79	0 or Δ - Use Observation Weights in SPWDC 1 - ω Not Use Observation Weights
б	80	P

FIGURE 1. OBSWGT PARAMETER CARD

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Field	Column	Contents	Code
1	1 - 42	Remarks	1
2	43 - 52	Diameter of Satellite (Meters)	3
3	53 - 62	Mass of Satellite (Kg)	3
4	63 - 72	γ (Reflectivity)	3
5	73 - 77	Not used	
6	78 - 79	Δ 2	
7	80	P	

FIGURE 18. VEHICLE CHARACTERISTIC CARD

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Field	Column	Contents	Code
1	1	Δ t Integration Mode (Δ - variable, 1-fixed)	2
2	2 - 11	∆t Minutes (positive or negative)	3
3	12	Bulge Perturbation	4
4	13	Drag Perturbation	4
5	14	Radiation Pressure Perturbation	4
6	15	New Epoch Mode (\bigcirc Rev)(1-Time)(2-Time of Last Obs)	
7	16 - 29	t (time in days since beginning of year)(Absolute Revolution Number)	3
8	30 - 36	Elements to Correct: n , a_{xN} , a_{yN} , o , Ω , i , m	4
9	37	Max. Number of Corrections	2
10	38	n Only Correction on the First Pass*	4
11	39	Δq Check*	4
12	40 - 47	Max. Δ q (KM)	3
13	48 - 55	ABSMX (KM)	3
14	56 - 63	ABSMX2 (KM/Sec)	3 3 3
15	64 - 71	n (RMS Multiplier)	3
16	72	Residual Output (A -Never)(1 - First Set)	-
		(2-Every Set)	
17	73 - 77	Not Used	
18	78 - 79	Δ 3	
19	80	P	

^{*}Applies only if 6-7 Elements are to be corrected.

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FIGURE 19. DIFFERENTIAL CORRECTION CONTROL CARD

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Field	Column	Contents	Code
1	1 - 10	a _{l.} (Absolute Error Criteria)	3
2	11 - 20	a a x	3
3	21 - 30	a a y	3
4	31 - 40	a a z	3
5	41 - 50	a _h _x	3
6	51 - 60	a _h y	3
7	61 - 70	a _h z	3
8	71 - 77	Not Used	
9	78 - 79	△ 4	
10	80	P	

FIGURE 2. ABSOLUTE ERROR CONTROL CARD

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Field	Column	Contents	Code
1	1 - 10	${f r}_{f L}$ (Relative Error Criteria)	3
2	11 - 20	r a _x	3
3	21 - 30	r a y	ڌ
4	31 - 40	r _a ₂	3
5	41 - 50	r h	3
6	51 - 60	r h y	3
7	61 - 70	r _h x	3
{ ,	71 - 77	Not Used	
9	78 - 79	Δ 5	
10	80	P	

FIGURE 21. RELATIVE ERROR CONTROL CARD

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Field	Column	Contents	Code
1	1	Δ t Integration Mode (Δ - variable) (1 - fixed)	2
2	2 - 11	Δt (Min)(may be negative if desired)	3
3	12	Bulge Perturbation	4
4	13	Drag Perturbation	4
5	14	Radiation Pressure Perturbation	4
δ·	15 - 16	Print Flag $\{1-t, \underline{r}, \underline{\dot{r}}, \{0, \omega, U, \}\}$ Add flag combinat $\{4-t, \Phi, \lambda_{E}, h\}$ of data	s for ion
7	17	Binary Tape Output	4
8	18	Prediction Reliability*	4
9	19	Punched Cards $(\underline{\iota},t)$	4
10	20 - 77	Not Used	
11	78 - 79	Δ6	
12	80	P	

*Must be a weighted 6 element or 7 element with drag differential correction run.

FIGURE 22. TIME PREDICTION CARD #1

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8 8 8	8	1	8	8	8	8	8	8	ŝ	f i	3	! !	8	8	8	8 8	8	:	8	8 (8 6	8	8	\$	8	ŧ	8	8 8	3 1	8		8	8	8 1	8 8		8	ŧ	8 1	8 (1	8	ŧ	1	8 (1	1	8	ŧ	8 1	8 (1	1		1	8 8	1 (1	. 8	9	8	8	8	8	8
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Field	Column	Contents	Code
1	1 - 12	Time in days since beginning of year	3
2	13 - 20	Δt (Min)	3
3	21 - 24	Number of output points	3
4	25 - 77	Not Used	
5	78 - 79	Δ 7	
6	80	P	

FIGURE 2°. TIME PREDICTION CARD #2

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Field	Column	Contents	Code
1	1	Δ t Integration Mode (Δ - variable) (1- fixed)	2
2	2 - 11	Δt (Min)	3
3	12	Bulge Perturbation	4
	13	Drag Perturbation	<i>i</i> .
4 5 6	14	Radiation Pressure Perturbation	4
6	15 - 16	Print Flag $\left\{ \begin{array}{l} 1-t, \ \underline{r}, \ \underline{\dot{r}} \\ 2-t, \ \overline{a}, \ \overline{e}, \ i, \Omega, \omega, \ U \end{array} \right\}$ $\left\{ \begin{array}{l} 4-t, \ \Phi, \lambda, h \\ 8-t, \ \rho, \rho, \end{array} \right\}$, A, h	Add flags for combination of data
7	17	Binary Tape Output	4
8	18	Prediction Reliance*	4
9	19 - 22	Sensor Number ($\triangle\triangle\triangle$ - Station Pred. Co. (XXXX - SEAI Tape)	ard 2 needed)
1.0	23 - 32	K - No. of Passes	2
11	33 - 42	△T (Min) (Either Side of Closest Appro	pach) 3
12	43 - 52	Δt^* (Min) (Output per Δt^*)	3
13	53 - 62	Minimum h (Deg)	3
14	63 - 77	Not Used	-
15	78 - 79	Δ8	
16	80	P	

^{*}Must be a weighted 6 element or 7 element with drag differential correction run.

FIGURE 24. STATION FASS PREDICTION CARD #1

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3333	2 3	3 3	3	3	3 3	3 3	3	3	3	3	3	3	3 :	1	3	3	3	3	3	3	3 :	3 :	3 :	; ;	1 3	3 3	1 3		3 :	3 :	3 :	3 :	3	3	3	3	3 .	3	3	3	3	3	3	3	3	3	3	3 :	3	3 :	3 :	3 :	3 :	3 :	3	3	1	3	3 :	3 :	3 :	3 :	3 :	3 :	3	3	3	3	3	3	3	3	3)
4444	H	1 4	4	4	4 (14	4	4	4	4	4	\$.	1 4	14	4	4	4	4	4	4	4	6 4	14	14	14	14	1 4	ŀ	,	4 4	,		4	4	4	4	4 .	4	4	4	4	4	4	4	4	4	4	4	4 .	4 4	4 4	4 4	4 4	14	14	14	14	4	1	14		, ,		4 .	4	4	4	4	4	4	4	4	4		ļ
5 5 5 5	ı ijs	5	5	5 !	5 5	5	5	5	5	5	5 :	5 :	; ;		5	5	5	5	5	5	5 !	5 !	5 5	5 5	5 5	5 5	;		5 5	5 :	5	5 :	5	5	5 :	5	5	5 :	5	5	5	5	5	5	5	5	5 :	5 :	5 :	5 :	5 :	5 :	5 5	5 5	5	;	; ;		j ;	5 5	5 (5 5	5 :	5 9	5 9	5	5	5	5	5	5	5	5	5	į
6656	įs	6	6	8 (6 6	6	6	S	6	6	6	1	; (•	6	6	6	6	5 i	6	6 1	5 (5 6	;		i 6			5 (5 (6 (6 (6	S	6	•	6	6	\$	•	ŧ	S	ŝ	\$	6	6	\$	6 8		6 (6 (5 (6 (1	1	3 (1		3 (6 (6 (6 (6 1	5 (5 (6	6	6	6	•	6	•	6	f	į
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Field	Column	Contents	Code
1	1 - 4	Station No.	1
2	5 - 14	$\Phi_{_{ m N}}$ Latitude (Degrees)	3
3	15 - 24	$\lambda_{\mathcal{W}}$ Longitude West (Degrees)	3
4	25 - 34	H (Meters)	3
5	35 - 77	Not Used	
6	78 - 79	∆ 9	
7	80	P	

Field	Column	Contents	Code
1	1	DC Flag	4
2	2	Prediction $({\stackrel{\wedge}{\Omega}}$ - no)(1-Time)(2-Station)	2
3	3 ~ 77	Not Used	
4	78 - 79	10	
5	80	P	

FIGURE 26. PROGRAM EXECUTION CARD

		1					7																		-	_																						_																						`	•
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2	,	i	š	ī	,	3	• [11			15	15	17	19	19	×	n	12 2	2	7	75	77	ä	'n	3	נונו נונו	2	ָנ נונו	H 1	, 15 1	63	, ,		4	47	42	43	ŭ	5	6	17 4		,	3 \$1	2	ม	9	4 :	6 5	,	*	š	ļ	2 6	3 6			ij	ě	×	*	71	ומו	ומ	,,	, ,	, . 8 T	, ,	. 7	
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5	5	5	5	5	5	5	5	5 5	5 5	5	5	5	5	5	5	5	5	5	5 5	5	5	5	5	5	5	5 :	5 9	5 5	;	5 5	;	5 5	5	5	5	5	5	5	5	5	5 ;	5 5	5	5	5	5	5	5 :	5 9	5	5	5	5	5 !	5 3	5	5	5	5	5	5	5	5 !	5 :	5 5	;	j 5	5	5	5	
6	6	6	6	6	\$	6	6	; (6	5	6	6	õ	6	6	6	6	6	5 (6	6	¢	6	í	6	6	6 (6 (6 (6 (6 (6	•	5	6	Ģ	è	b	6	5	6 (6	; (\$	\$	•	6	\$ (6 (•	•	6	•	\$ (5 (i	•	•	ŧ	•	í	6	•	6 (1	} (, (6	6	Ş	
ì	7	7	7	7	7	7	7	1	7	7	7	7	7	7	7	7	7	7	1	7	7	7	7	7	7	1	7	1	1	1	1	1	7	7	7	1	7	7	7	7	1	1 1	7	7	7	7	7	7 7	1	1	7	1	7	7 7	1 1	7	7	7	7	7	7	7	7 7	7	1 1	1 1	17	7	7	7	1
1	8	1	8	8	ŝ			1		ŧ	8	8	8	1	8	ŝ	8	•) (8	ı	1		ŧ	8	1	3 () () (8) (8	1		ŧ	ŧ	8	ŧ	8	8 8	1	H	1			8	;	8 (l	•		ı	1	8 (1	•		1		ŧ	1	8	8 (3 (1	1 8			•	1	1
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9 !	} {	9	9	9	9	9	9	9 9	9	, ,) (9	1	9	9	9	9	9	9	9	9 !	9 !) (9 9	9	9	9	9	9	9 (9 5	1	9	\$	1	9 9	9	9	9	9	9	9	•	9	1) (1	! 1	3	9	9	9	1

Field	Column	Contents
1	1 - 8	If ID CARD - 70WEIGHT If END CONTROL CARD - ENDSIGMA
2	9	$^{11}8_{2}$ Multiple Punch

FIGURE 2 . WEIGHT TAPE CONTROL CARD

1		2		3	}	-			4							-	5						6					_			7			K	3												•																					\ 	<u> </u>
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Field	Column	Contents
1	1 - 3	Sensor Number
2	4	 0 - Sigma Data is for all observations from a ερecified sensor 2 - Sigma Data is for the next observation only
3	5 - 8	Not Used
4	9 - i6	σ ₁ ρ(km)
5	17 - 24	$\sigma_2^- \dot{\rho}(km/sec)$
6	25 - 32	σ_3 A or α (degrees)
7	33 - 40	$\sigma_4^{}$ hor δ (degrees)
8	41	11_{8} Multiple Punch

NOTE: If a sigma is not input, leave the field blank

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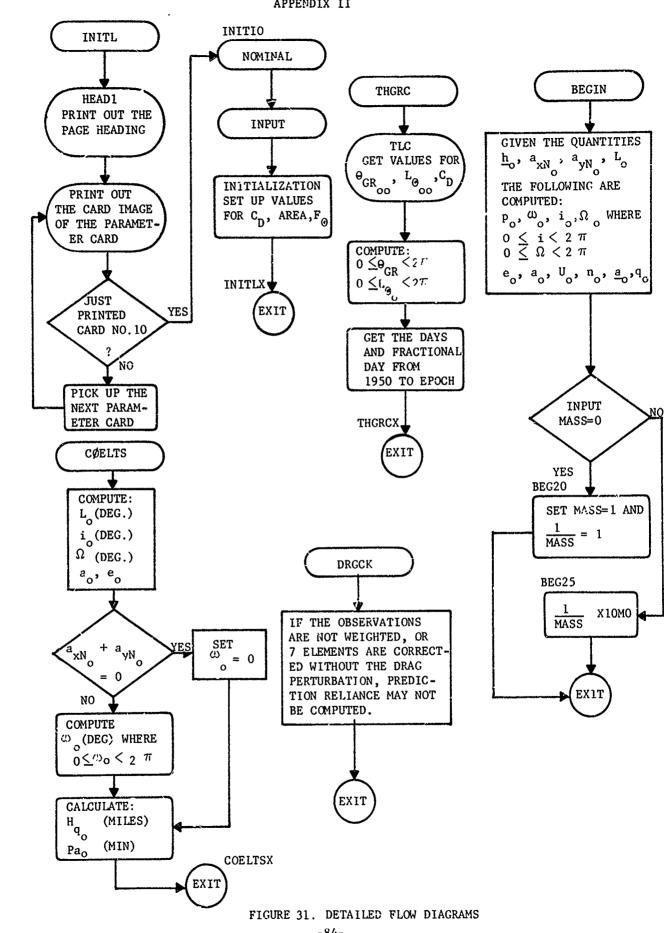
Field	Column	Contents
1	1 - 3	Sensor Number
2	4	1 - Parameter Data is for a function
3	5	Δ or 0 - if the last parameter is contained on this card*
		1 - if parameters follow on next card
4	6 - 8	Not Used
5	9 - 16	Function Identifier (left adjusted)
6 - 13	17 - 80	P ₁ through P ₈ *

*The last parameter must be followed by the 11_{8_2} multiple punch in the next field or on the next card if necessary.

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Field	Column	Contents
1	1 - 3	Sensor Number
2	4	1 - Parameter data is for a function
3	5 - 8	Not Used
4	9 - 16	Function Identifier
5	17 - 24	P _g
6	25 - 32	P ₁₀ *

^{*}The last parameter must be followed by the 11_{8_2} multiple punch in the next field.



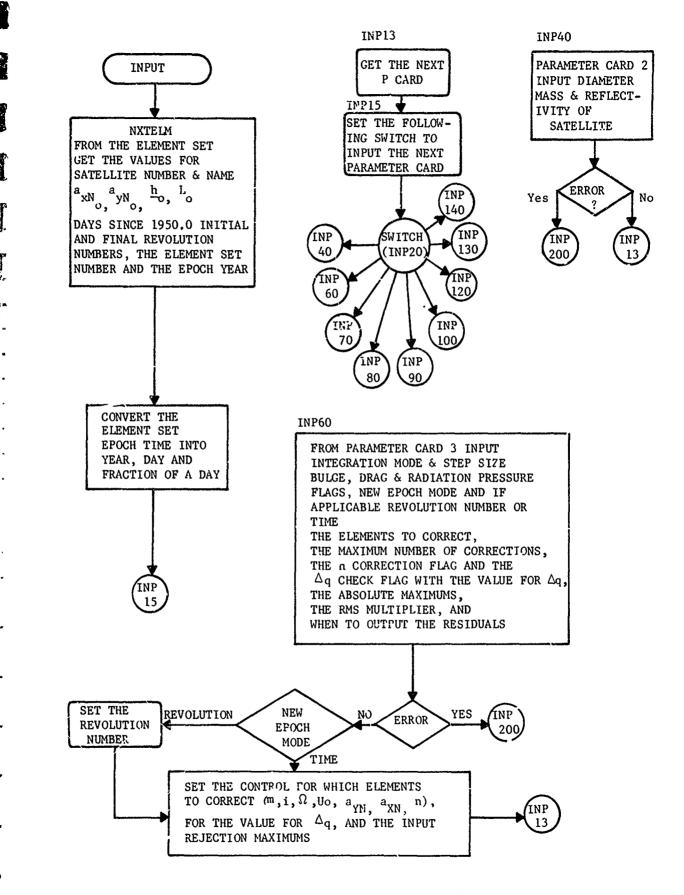
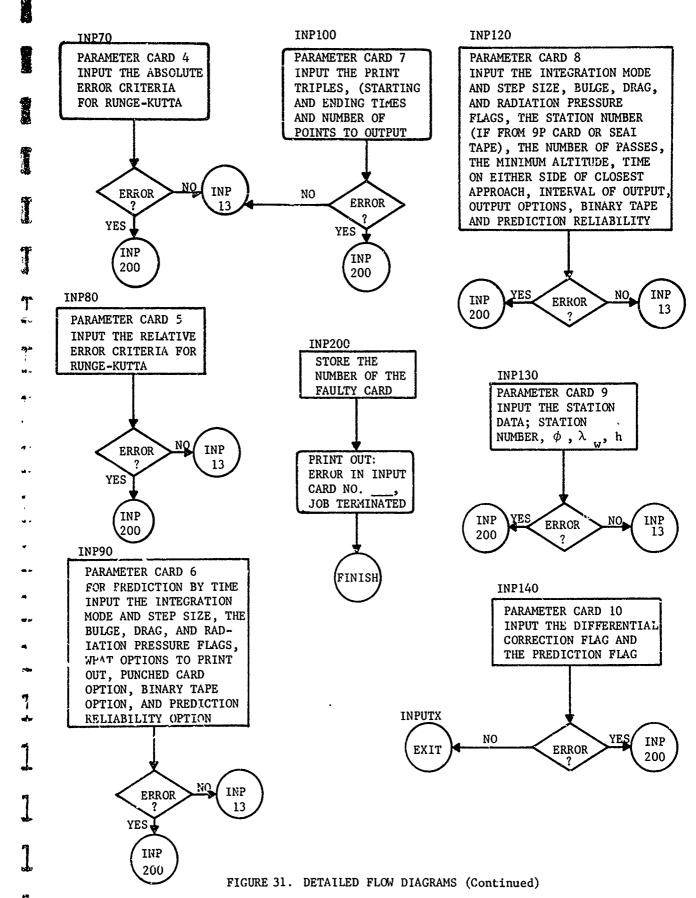


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)



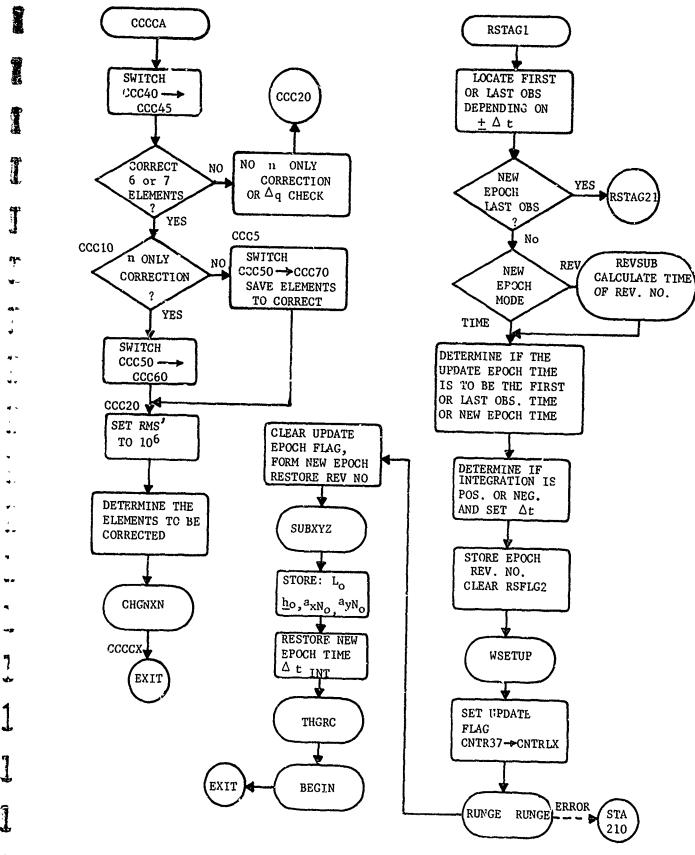
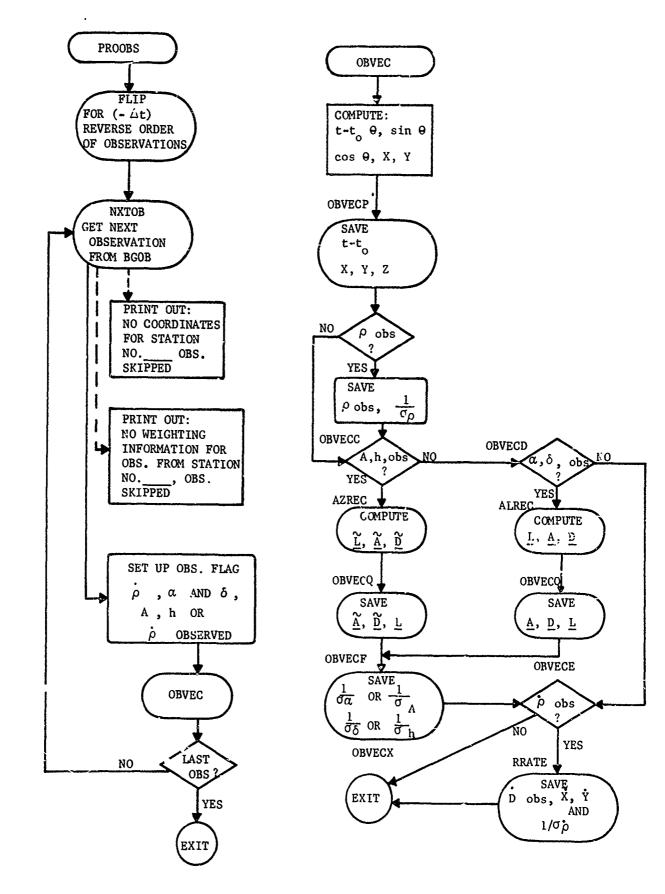


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)



FIGUET 31. DETAILED FLOW DIAGRAMS (Continued)

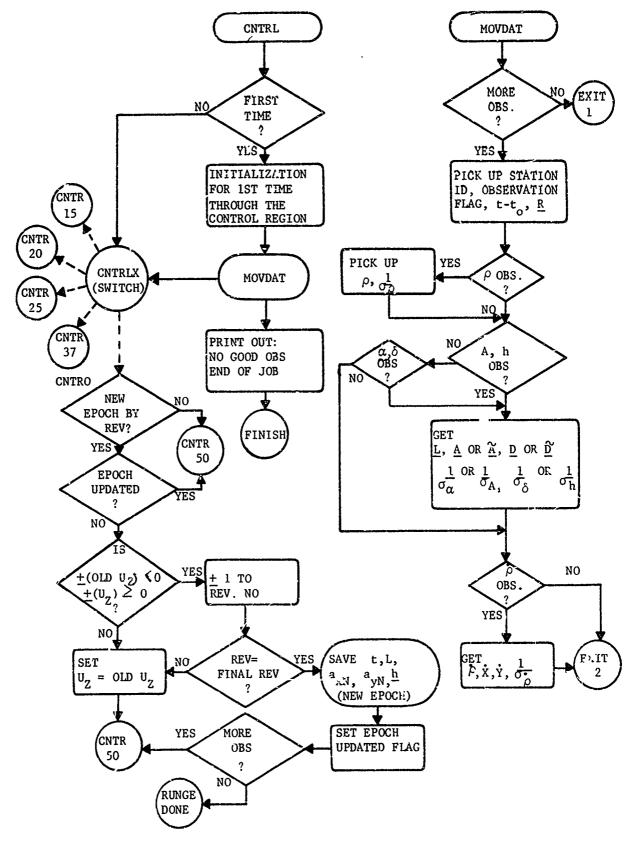


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

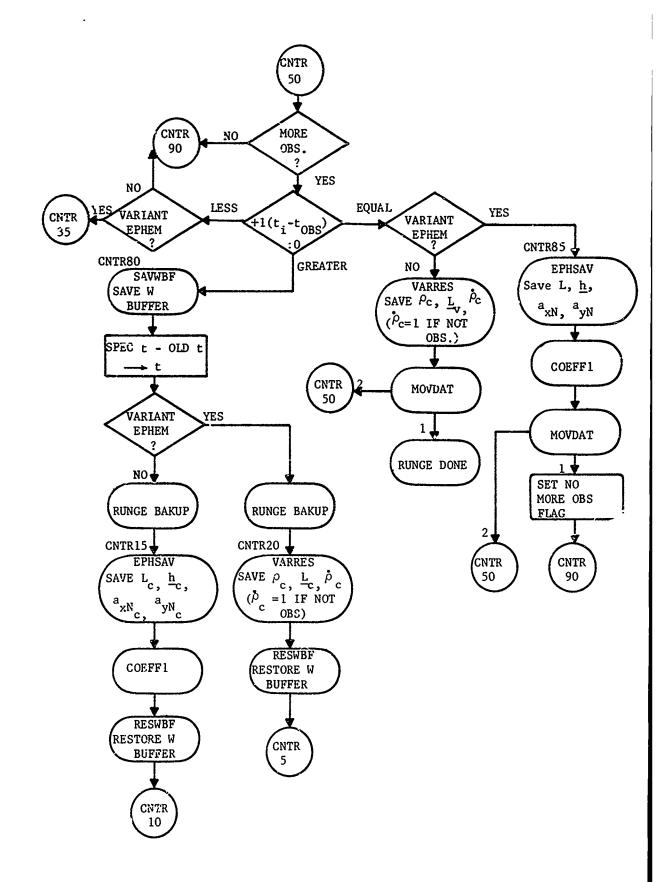


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

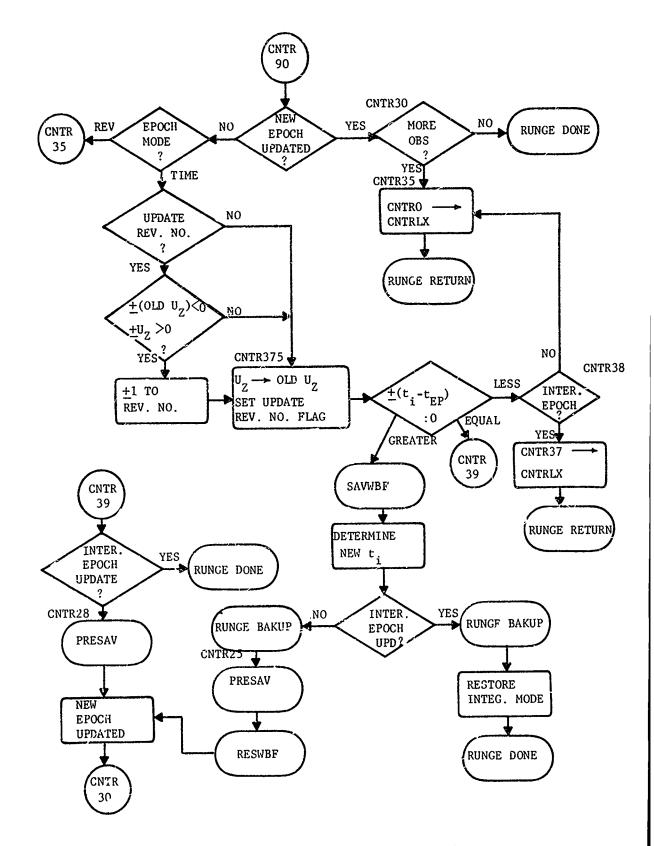
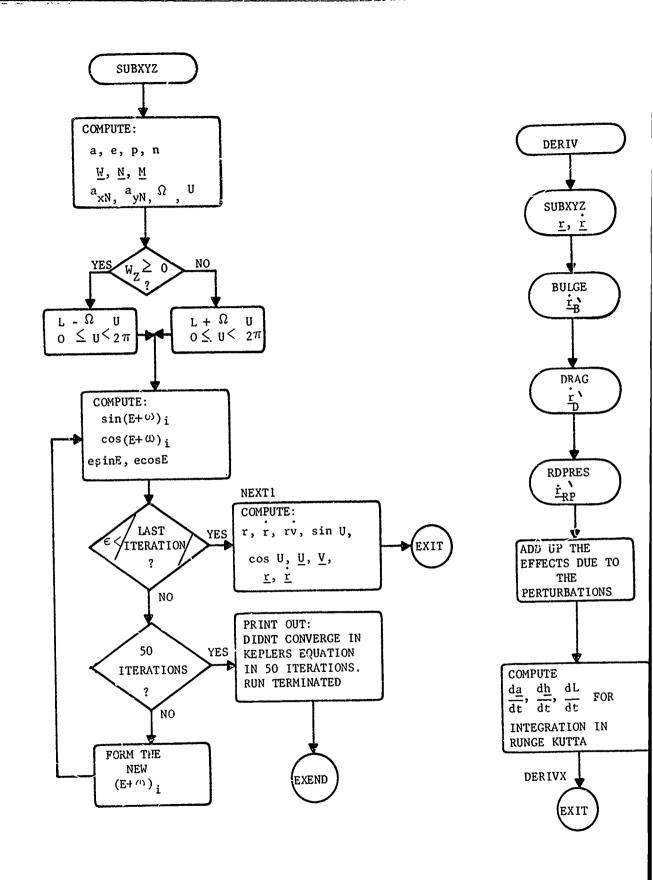


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)



1.

FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

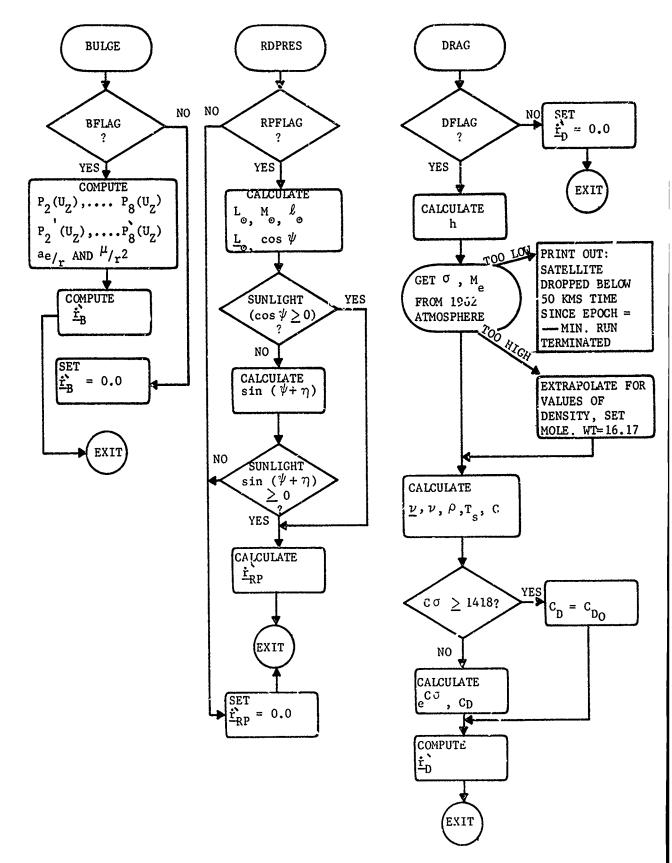
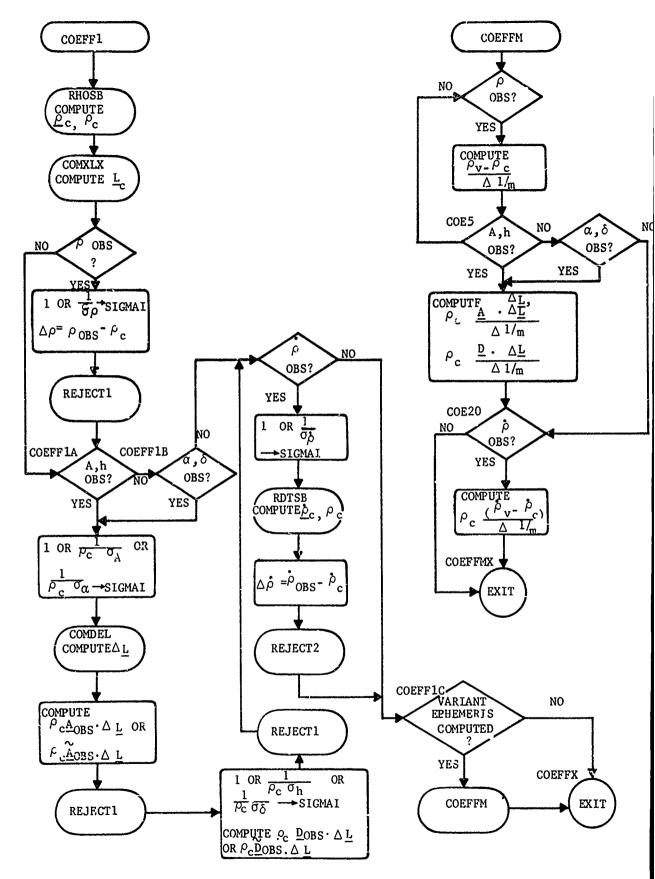


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)



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FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

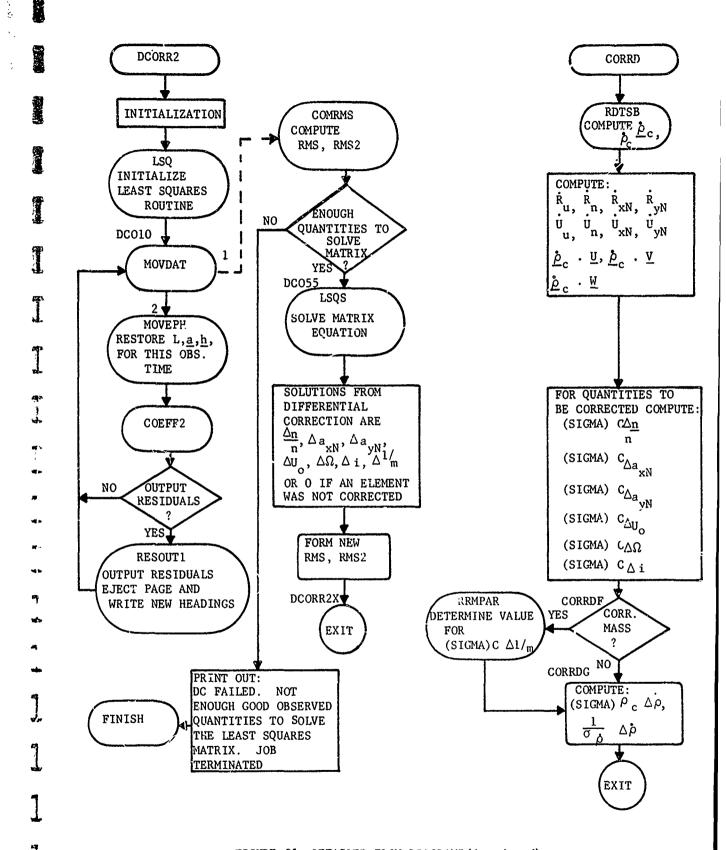


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

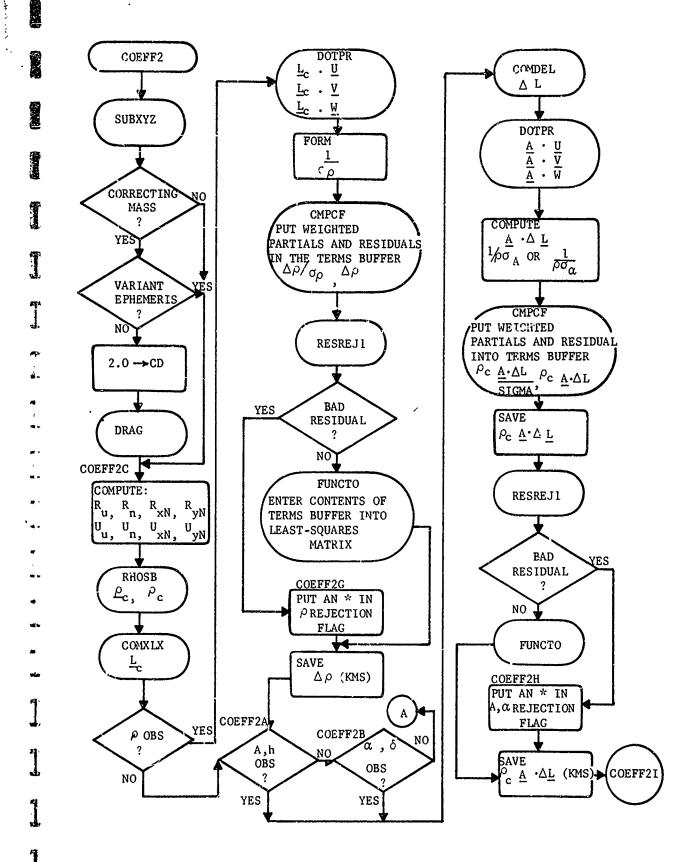


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

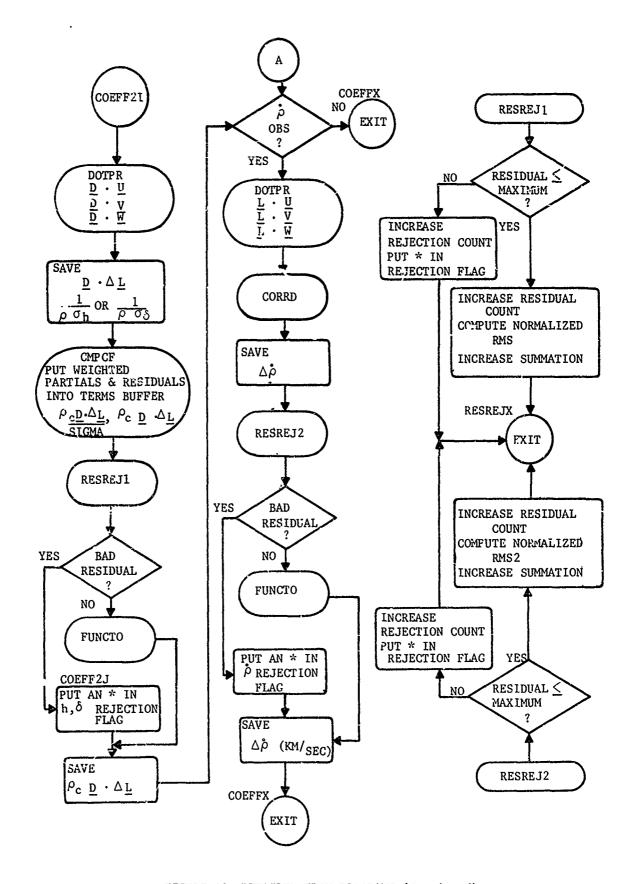


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

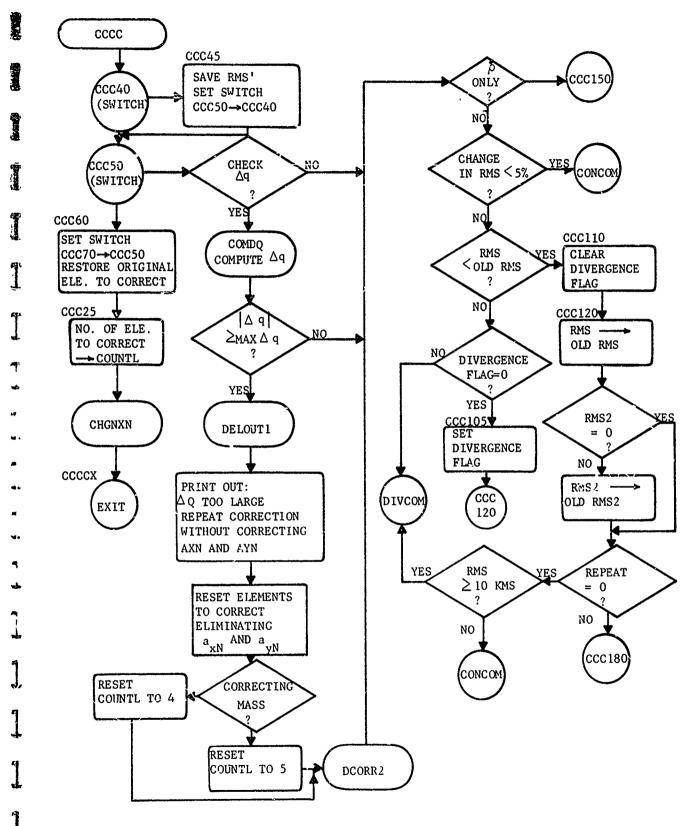


FIGURE 11. DETAILED FLOW DIAGRAMS (Continued)

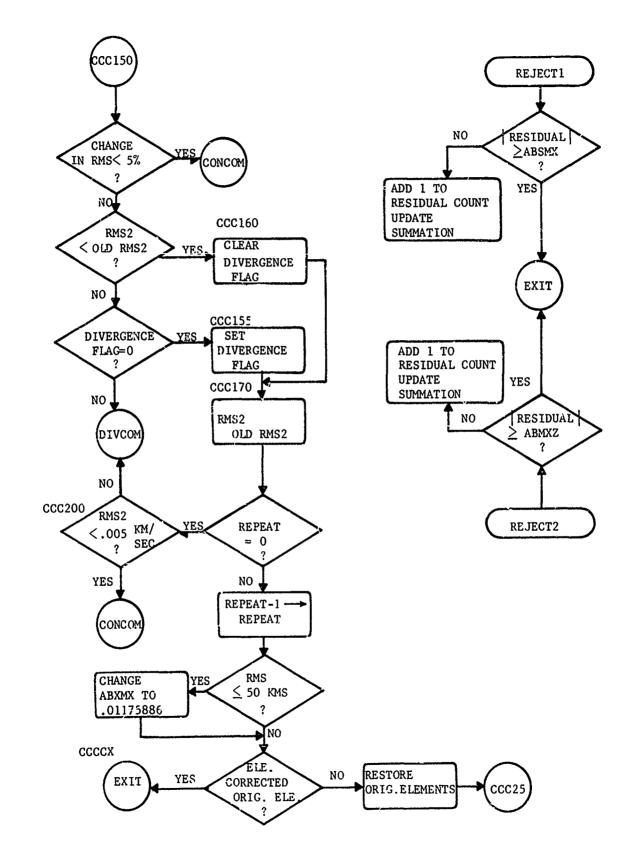


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued)

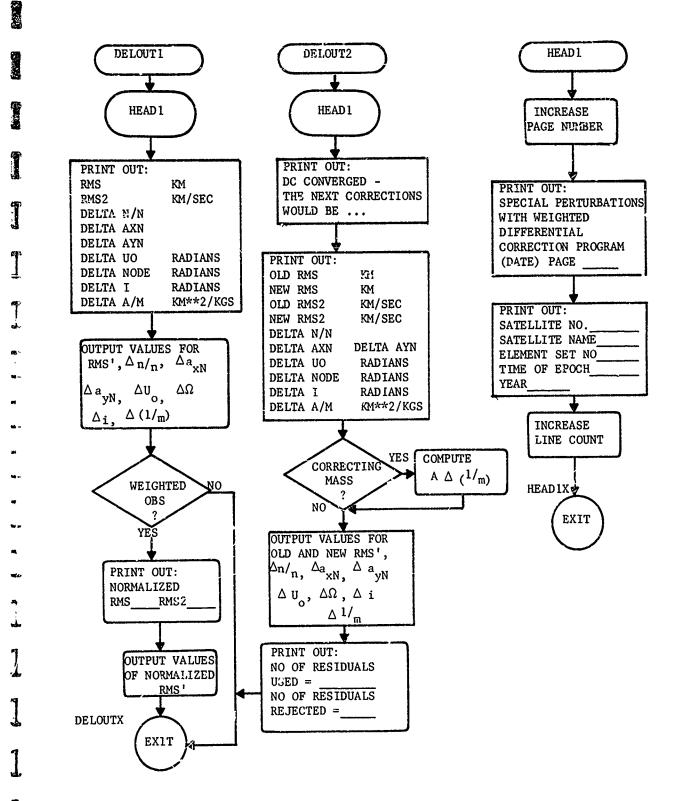


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued) -100-

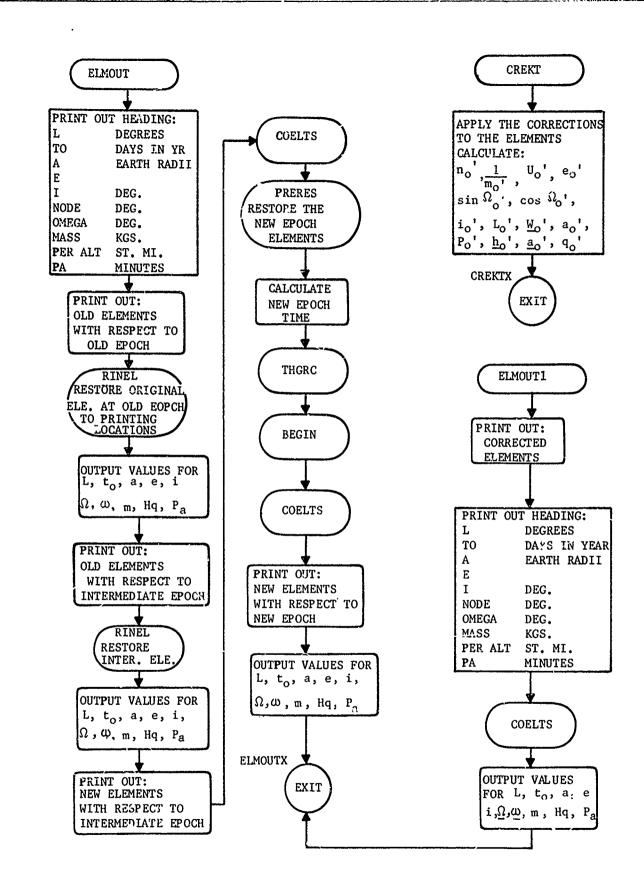
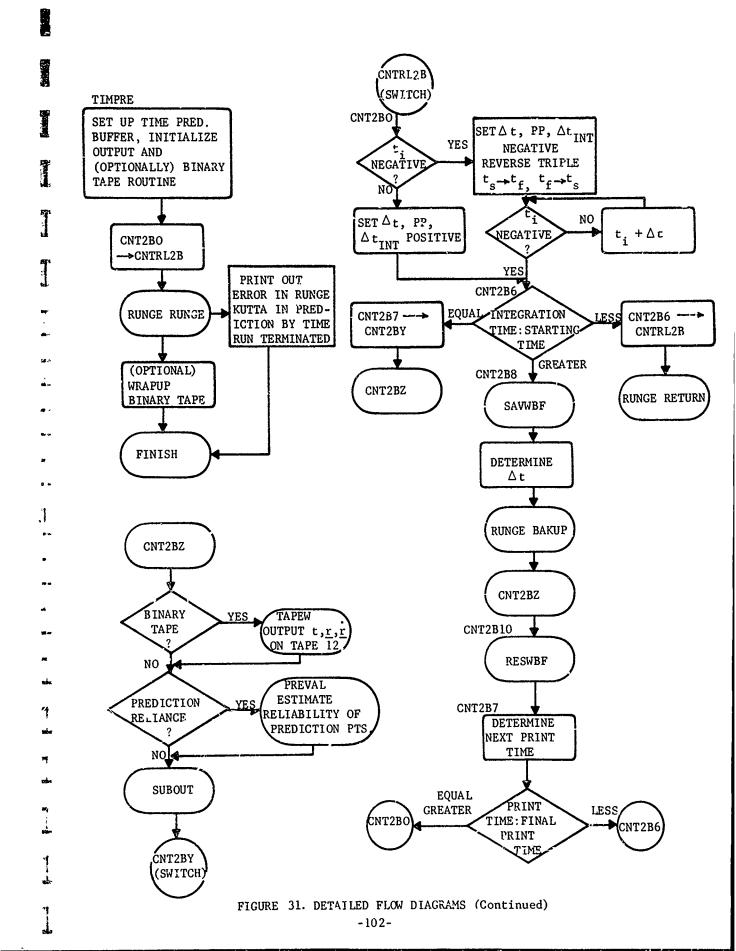


FIGURE 31. DETAILED FLOW DLAGRAMS (Continued) -101-



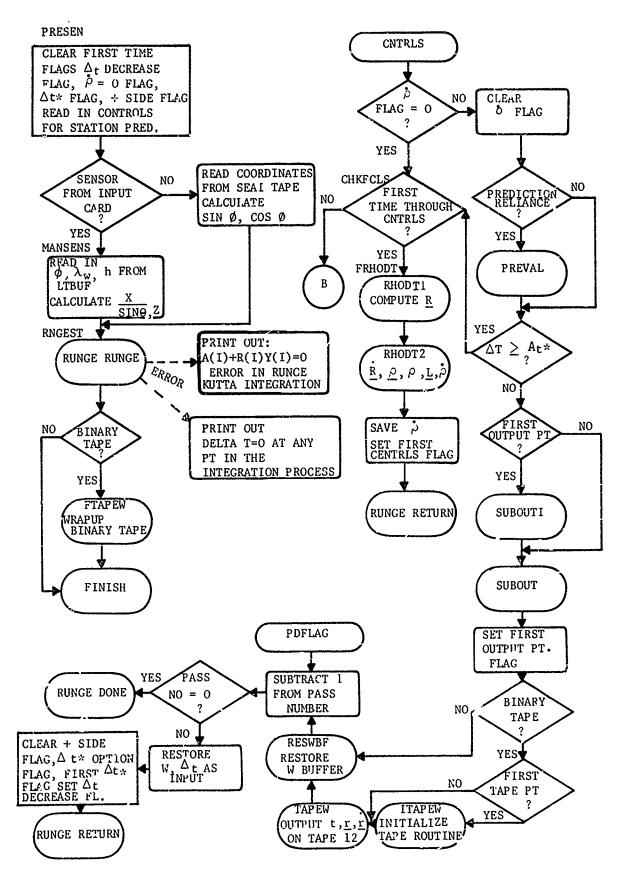
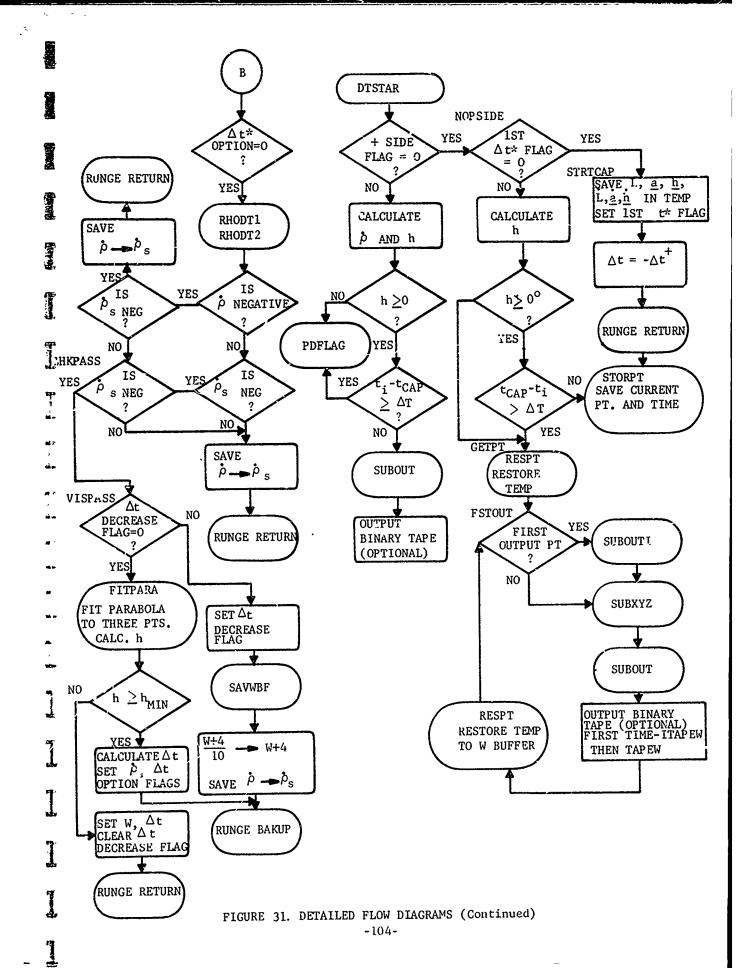


FIGURE 31. DETAILED FLOW DIAGRAMS (Continued) -103-



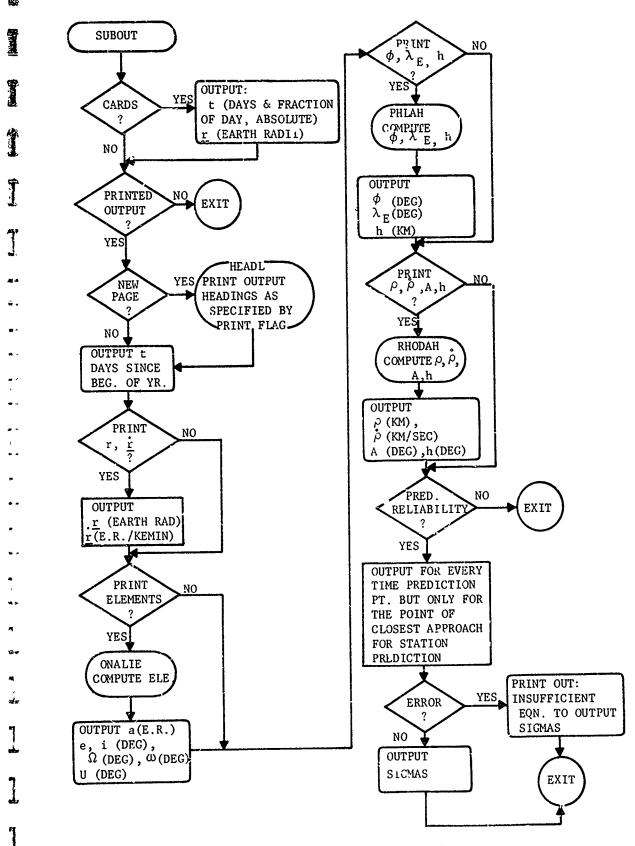


FIGURE 31 DETAILED FLOW DIAGRAMS (Continued)

APPENDIX III

PROGRAM GLOSSARY*

SYMBOL	DESCRIPTION					
A	a					
ACCONT	Total residual count					
AE	a e					
ALFLG	A, α residual flag					
APRINT	Output location for a_0 Satellite area $(\pi \frac{d^2}{4})$					
AREA	Satellite area $(\pi \frac{d^2}{4})$					
ASTK	*					
AXGR	a v x					
OXA	a _x					
AYGR	a y					
OYA	ay					
AZGR	ay az					
AZIM	Aziouth					
AZO	a _z o					
BFLAG	Bulge flag					
BGOB	Reformatted OBLOC (16 word format)					
BTFLAG	Binary tape flag					
- •	- 4					
CAPD	D (DERIV)					
CC	C (DRAG)					
CCC40	Switch for CCCC first time					

^{*}Includes (1) SPWDC program symbols and (2) all symbols not appearing in the SPS B-2 Assign Deck. Underscored, capitalized notations refer to subroutines in the program.

CCC50 Switch for CCCC n only correction on first pass $C_D = 0.92 (DRAG)$ CDO CDO(DRAG) CD First time through flag (CNTRL) CFLAG1 CFLAG2 No more observations flag (CNTRL) CFLAG3 Variant, normal ephemeris flag (CNTRL) CFLAG4 New epoch by revolution or time flag (CNTRL) CFLAG5 New epoch updated flag (CNTRL) CNFLAG Correct n flag CNTRLX Switch for D. C. Control Region (CNTRL) CONTEST Convergence test (5%) (CCCC) $\cos \epsilon = 0.9174469$ COSEPS cos ψ COSPSI Same as COUNTL COUNTLR COUNTL Number of elements being corrected COUNTR Same as COUNTL DCAPT ∆ T (Station Prediction) Differential Correction flag DCFLAG1 $\frac{v_{co}^{3}}{4\epsilon\sigma_{s}}\left(\frac{cm^{3} kemin^{3} o_{K}^{4}}{gm radii^{3}}\right) = 2.419012831x10^{21}$ DCONT1 $\frac{-0.6378150\times10^{10} \text{ A}}{2} \quad \left(\frac{\text{cm}^3 \text{ kg}}{\text{gm radii}}\right)$ DCONT2 D_{c} DC D (DERIV) **DDGR** DELTAQ Δq DELTATO $\Delta \left(\frac{1}{2}\right)$ DEN7

DENOM $1 + \sqrt{1 - e^2}$ (SUBXYZ)

DFLAG Drag flag

DGR D (DERIV)

DIAM Effective diameter of the satellite

DIVFL Divergence flag

DLFLG δ , h residuals flag

DLT1M $\triangle \left(\frac{1}{m}\right)$ (DCORR2)

DLVX \triangle x

dlvy $\triangle v_y$

DLVZ \triangle ∇

DQFLAG Delta q check flag

DQN Maximum $\triangle q$ for $\triangle q$ check

DRSDL $\rho_{c} \underline{D} \wedge \Delta \underline{L}$ (kms)

DTASK Δt^* (Station Prediction)

DT Δt (prediction by time)

DTSROPT Δt^* option flag (Station Prediction)

E2VGR $-e^2$ V

ECSIG eC O

ELEV h (RHODAH)

ELFLAG1 Error flag for prediction reliance ELFLAG Prediction Reliance Flag

ELFLAG Prediction Reliance Flag

EOCHK Eccentricity check - variant ephemeris vs. analytical computation for mass

	ЕРНЕМ	Buffer for saving ephemeris L, <u>a</u> ,	<u>h</u>
1	EPRINT	Output location for e	
	EPS1	ϵ (RAD) for Kepler's Eqn = 10^{-8}	
Ŧ	FOBHR	Output location for observation time	me - hr
	FOBMIN	Output location for observation time	me - min
gs (FOBSEC	Output location for observation time	me - sec
ni -	FRDAY	Integral days since beginning of y	ear
3	FRFLAG	Punched card output flag (SUBOUT)	
a.	FRFRAC	Fractional day	
N	FRSTFLG	First time flag (Station Prediction	n)
. .	FRTIME	Days since beginning of year (SUBO	UT)
• •	FSTCTLS	First time flag (Station Prediction	n)
•	FSTDTSR	First Δ t* Pass flag (Station Pred	iction)
•	FSTPTW	First printed output flag	
• •	FSTSOUT	First printed output flag (Station	Prediction)
	GAMMA	Reflectivity of satellite	
~~	н2мн1	н ₂ - н ₁	(TBINT)
~	н2мн	H ₂ - H	(TBINT)
	HCON1	$3/2 \text{ f}^2 = 0.0168571736 \times 10^{-3}$	(CALH)
1	нмн1	н - н ₁	(TBINT)
ø.		1	

HMIN	h _{mi}	(Station	Prediction)
	m 7 . 3	•	•

INELT2 Beginning storage location for original elements

INELT Beginning storage locations for updated elements

INP20 Switch for Parameter Card Input (INPUT)

IPRINT Output location for i (deg.)

JBUF Kozai Values for J_2 through J_7

KEORTM $Ke/\sqrt{\mu} = 0.07436574$

KNTRL Which elements to connect $(m, i, \Omega, U_0, a_{yN}, a_{xN}, n)$

LINECT Line Count

==

LPRINT Output location for L_{0} (deg.)

LSQBUF Least Squares Buffer

LSTT Last t (PROOBS)

LTBUF Buffer for Controls for prediction

MASSO Original mass of satellite (Kgs)

MASSPR Output location for mass

MASS Program value of mass

MAX2 ρ rejection criteria

MAX ρ and angle rejection criteria

ME M_{ρ} TBINT

MFLAG1 Flag to compute mass correction analytically or by

variant ephemeris

MSPRK 7905 (Prediction Reliance)

MU μ

NLINE Number of lines to be output

NOPASS Pass number (Station Prediction)

NPRINT Output location for Ω_{Ω} (deg.)

N n (BULGE)

NII v

NUX ν

NUY ν

NUZ ν_z

OBDAY Day of Observation

OBFLG Observation flag (What quantities were observed)

OBMO Month of observation

OBYEAR Year of observation

OFLAG4 Residual sets to output flag

OFLAGS	Set up by OFLAG4	(Output residuals or not)
OLDRMS2	Old RMS for range	rate
OLDRMS	Old rms for range	and angles

OMEGAP Output location for
$$\omega_c$$
 (deg.)

OPRTESQ
$$1 + \sqrt{1 - e^2}$$

PBUF
$$P_2$$
 through P_8 (BULGE)

PISUN
$$\pi_{o} = 4.929316613$$

PNPRINT
$$P_N$$
 output location

PP <u>+ 1</u>

PREDBF Buffer to save new epoch time, L, \underline{a} , \underline{h}

PRTIME Time of new epoch

PRTIM Buffer for time prediction

PYEAR Output location for year (IHEAD1)

QQ Temporary location

RCNT2 Residual count for ρ

RCNT Residual count for ρ and angles

RDOTOR $\dot{r}/_{r}$

RDTFLG ρ = 0 flag (Station Prediction)

REJCNT Number of residuals rejected

REJFLG Rejection flag if any observation quantity is

rejected

REV Revolution number

RGFLG Range residual flag

RGSDL $\triangle \rho$ (km)

RHODT3 Storage location for RHODT

RHOO $\rho_{_{O}}(^{gm}/_{_{Cm}}3) = 0.001225$

RHO ρ (<u>DRAG</u>)

RMS 2 RMS for range rate

RMSCHK 50 km RMS Root mean square for ρ , and angles ROVA r/a $2e_{\odot} = 0.03345100$ RPCON1 $5/4e_0^2 = 0.0003496779$ RPCON2 $F_{o} = \gamma P_{o} A \frac{\text{Kg radii}}{\text{kemin}^2}$ RPCON3 **RPFLAG** Radiation pressure flag RPT Number of passes through D.C. RRFLG Range rate residual flag RRSDL $\Delta \rho$ (km/sec) Flag for CNTRL for intermediate epoch RSFLAG RSFLG2 First time through CNTRL for intermediate epoch RSFLG3 Storage location WFLAG (RESRET1) SATEL Satellite number SATL Output location for Satellite Number Buffer for saving W buffer before going to Runge-SAVBUF Kutta back-up routine Storage location for cell 0 SAVEO SAVE3 Storage location for cell 3 \underline{r}_{OBS} , \underline{W} $\sqrt{\underline{r}_{OBS}}$, \underline{r}_{OBS} SAVEM

SENSNO

Sensor number (Station Prediction)

SETRD2	Addrace	after	126+	c=11	in	nroceced	observation	huffer
GUIKUL	varies?	arcer	1a3 c		~!!	processea	ODSET AGETOR	Darrer

SIGMA1
$$\frac{1}{\sigma_{\rho}}$$

SIGMA2
$$\frac{1}{\sigma}$$

SIGMA3
$$\frac{1}{\sigma_{\alpha}}$$
 or $\frac{1}{\sigma_{A}}$

SIGMA4
$$\frac{1}{\sigma_{\delta}}$$
 or $\frac{1}{\sigma_{h}}$

SIGMAI
$$\frac{1}{\sigma_{\rho}}$$
 for ρ_{OBS} , $\frac{1}{\rho_{c}\sigma}$ for angles observed

SIGMA
$$\sigma$$
 (DRAG) (TBINT)

SINBOTH
$$\sin (\psi + \epsilon)$$

SINEPS
$$\sin \epsilon = 0.3978584$$

TCAP T (Station Prediction)

TEMP1 Temporary

TEMP2 Temporary

TEMP3 Temporary

TEMP Storage location for FRTUME

TERMS Least Squares Buffer

TF t_f (final output time - time pred)

THE TA θ

TLFLAG Point of closest approach flag (Station Prediction)

TMPEND Temporary Ending address (Station Prediction)

TMPLOC1 Temporary

TMPLOC2 Temporary

TOPR Same as TO

TOYPR Cutput location for epoch year

T t (minutes since epoch)

TSI Beginning time point (Time Prediction)

TS Ts (OK)

VFLAG) Variant Ephemeris Flag

i r	WFLAG	Weight Flag	
	W	Fixed or Variable integration mod	e (Runge-Kutta)
-	WSUM2	Normalized RMS for range rate	
	WSUM	Normalized RMS	
2 ,	X10M0	$\frac{1}{m_0}$	
Î	XBDGR	x' _B	(BULGE)
	XDGR	× _B	(<u>DERIV</u>)
Ţ	XDTGR	x _D	(<u>DRAG</u>)
Y -	XLAMD	$\lambda_{\mathbf{E}}$	
1 ahv	XLSNSBX	Lxo	(RDPRES)
1	XLSNSBY	L yo	(RDPRES)
. 	XLSNSBZ	Lzo	(RDPRES)
	XLSUN	L _e (rad)	(RDPRES)
F¶	XLSUNT	l (rad)	(RDPRES)
]	XMPER	Kr/radii	
1	XMSUN	M (rad)	(<u>RDPRES</u>)
	XNSUN1	$n_0 (\frac{\text{deg}}{\text{day}}) = 0.9856473354$	(THGRC)
1	XNSUN	$n_{o} (^{rad}/_{min}) = 0.01194638282 \times 10^{-1}$	0 ⁻³ (<u>RDPRES</u>)
Ä	XRDGR	x _{RP}	(RDPRES)

3

YBDGR	ý _B	(BULGE)
YDGR	ÿ `	(DERIV)
YDTGR	ŷ' _D	(DRAG)
YRDGR	ÿ _{RP}	(RDPRES)
ZBDGR	\dot{z}_{B}^{\prime}	(BULGE)
ZDGR	ż`	(<u>DERIV</u>)
ZDTGR	ż' _D	(DRAG)
ZRDGR	ż _{RP}	(RDPRES)

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